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THE SEPTEMBER SCIENTIFIC MONTHLY

Edited by

J. McKEEN CATTELL, F. R. MOULTON AND WARE CATTELL

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NEW BOOKS OF SCIENTIFIC INTEREST

Atoms in Action. G. R. HARRISON. 2nd ed. Illustrated. xii + 401 pp. $3.50. September, 1941. Morrow.

The world of creative physics is described in this non-technical book. The reader is told of the part energy and the electron play in modern life and is given a view of the extent to which the principles of physics hold true in guiding all activities.

An Introduction to Television. C. J. HYLANDER and R. HARDING, JR. Illustrated. xviii + 207 pp. $2.00. 1941. Macmillan.

The authors of this book have attempted to present a lucid and nontechnical account covering the historical development of television; an explanation of the present type of television camera, television broadcast, and receiver; and the electrical principles involved.

Physical Climatology. H. LANDSBERG. Illustrated. xii + 283 pp. 1941. Pennsylvania State.

Emphasis in this textbook is placed on climatic methods so that it can serve for reference and instruction for the beginning climatologist. Its chapters discuss collection and use of climatic data, climatological elements, composition of climatic elements and applied climatology.

Climate and Man. Illustrated. xii + 1248 pp. $1.75. 1941. U. S. Government.

Designed to aid farmers, a large part of this volume is devoted to a detailed discussion of the relation of climate and weather to crops. The second half of the book contains maps and tables of data on climate in all parts of the United States intended to assist farm operations in agricultural communities.

Applied Science. C. W. BANKS. viii + 212 pp. Illustrated. $1.75. 1942. Wiley.

This textbook discusses applications of the principles of physics, mechanics, strength of materials, hydraulics, heat, light and electricity. The intention of the author has been to explain the use of theoretical principles in practical problems by means of simple mathematical processes and few fundamental formulas.

Creative Factors in Scientific Research. A. L. PORTERFIELD. xi + 282 pp. $3.50. November, 1941. Duke.

This critique of scientific methods, intended to be of interest to biologists and physical scientists as well as to social scientists, studies the interplay of psychological and cultural factors in the development of science. Subject and name indexes are included.

Motivation and Visual Factors. BENDER and others. xix + 367 pp. 1942. Dartmouth.

The authors of this volume, through the study of psycho-portraits based upon tests, interviews, and an autobiography, have arrived at the conclusion that visual factors, even extreme deviations, do not in and of themselves cause maladjustment. The report has been drawn from the study of twenty college students.

Southwestern Archaeology. J. C. MCGREGOR. Illustrated. x + 403 pp. $5.00. 1941. Wiley.

This book is intended as an introduction to the archaeology of the Southwest. The first part presents a theoretical and general background applicable to archaeological work in any field; the second part is an historical reconstruction of the prehistoric Southwest. Bibliographies are included.

A Short History of Science to the Nineteenth Century. C. SINGER. Illustrated. xii + 399 pp. $3.00. 1941. Oxford.

Written for the general reader, this book is an elementary survey of the development of knowledge of the material world. It is an outline sketch in historical perspective that discusses the emergence of the leading scientific ideas from Greek times to the nineteenth century.

The Methodology of Pierre Duhem. A. LOWINGER. 184 pp. $2.25. November, 1941. Columbia.

This is a study of a Frenchman who has done work in physics and the history of science and whose methodological ideas have influenced logical thought in the United States. The author begins with a non-technical introduction to the philosophy of science.

College and University Museums. L. V. COLEMAN. Illustrated. viii + 73 pp. $1.25. 1942. Waverly.

This book is for presidents and trustees of American colleges and universities. Campus museums of all kinds are considered, and even the smallest teaching collections are looked upon as museums. The material collected into the book is the result of years of observation.

Doctors Anonymous. W. M. GERMAN. xviii + 300 pp. $2.75. 1941. Duell, Sloan and Pearce.

The author, a pathologist himself, tells for the layman the story of laboratory medicine, a field not widely understood. He presents the history of pathology, a tour of analysis through a modern laboratory and many stories and incidents connected with the work of the important man behind surgical work.

Famous Inventors for Boys and Girls. I. EBERLE. Illustrated. 130 pp. $2.00. 1941. A. S. Barnes.

Fourteen inventors who seem to the author to have most strongly affected the progress of the world through their inventions are included in this book. The biographical sketches are accompanied by contemporary portraits of the inventors and pictures of their inventions. The book is intended to stimulate further study.

Under the Sea Wind. R. R. CARSON. Illustrated. xii + 316 pp. $3.00. 1941. Simon and Schuster.

A cross-section of shore-line life, this book describes the life of the birds, the fishes, the jellyfish, and the crustaecae that follow the fringe of the sea from arctic to antarctic waters. The book contains an illustrated glossary of animals and plants of the sea.

THE SCIENTIFIC MONTHLY

SEPTEMBER, 1942

FOSSIL FORESTS OF THE GREAT COAL AGE

By Dr. RAYMOND E. JANSSEN

GEOLOGIST, EVANSTON, ILLINOIS

A knowledge of the past, however imperfect, adds to the attractiveness of the present.—*A. C. Seward.*

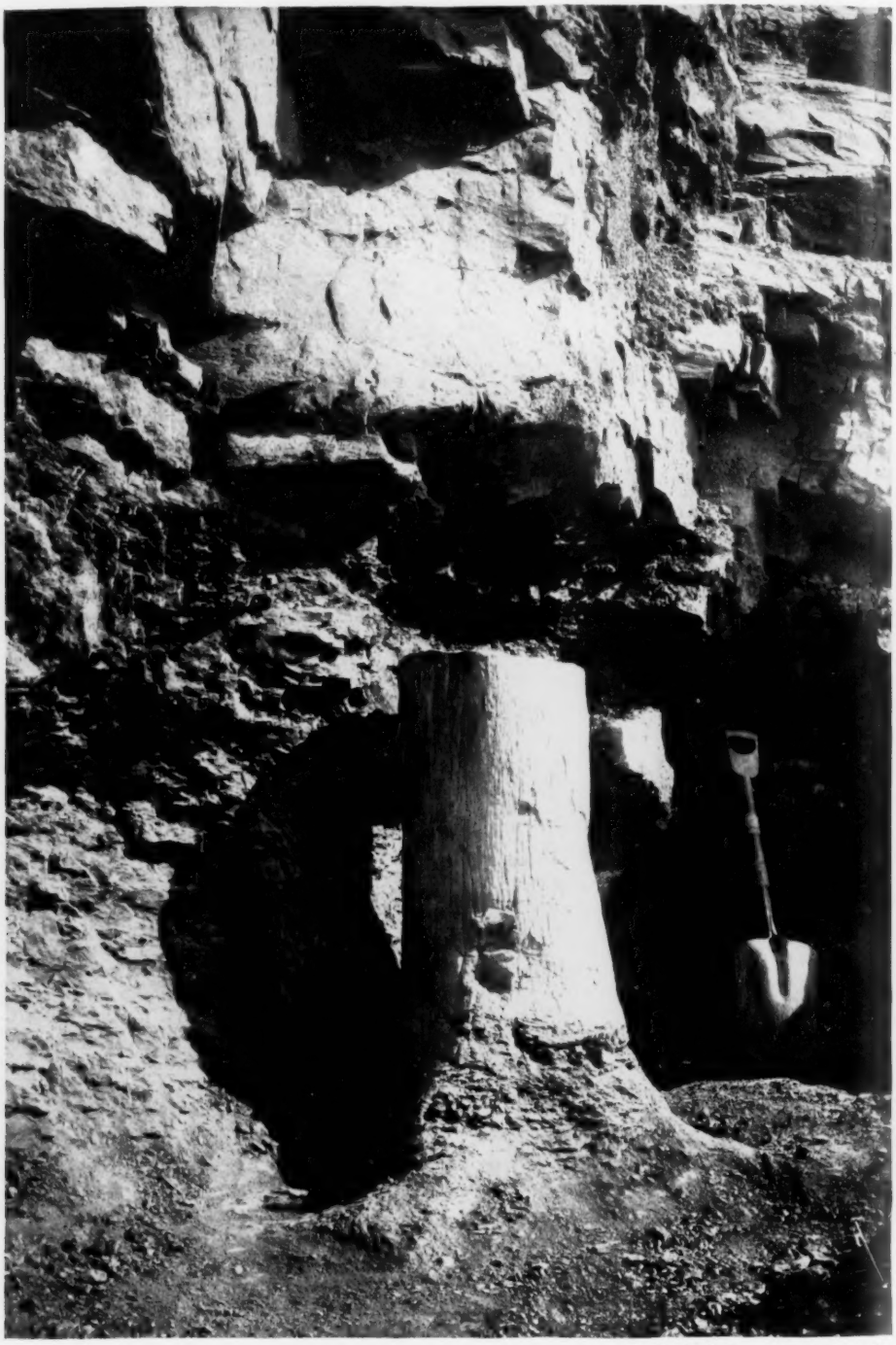
NEXT to soil and water, coal still remains the world's most vital natural resource. It was coal which made possible the melting of iron and its refinement into steel because its burning produced a hotter fire than man had ever been able to kindle before. Thus, by the use of coal, man made iron his slave, converting a medieval world into a modern one. But the use of coal for fuel was only preliminary to much wider uses. It has become the raw material from which a thousand products are made.

Coal has made possible mechanical refrigeration; thus it supplies us with both heat and cold. Coal gives us numerous kinds of plastics, chemicals and dyes, as well as sweetly smelling perfumes, flavoring extracts and sturdy fabrics. It is used for the manufacture of dynamite and ammunition, disinfectants and synthetic gasoline. Perhaps most important of all is its use as a source of medicines,

Field Museum of Natural History

FIG. 1. A FOREST OF THE GREAT COAL AGE

AS RECONSTRUCTED AT THE FIELD MUSEUM. THE PRINCIPAL TREES ARE *Sigillarias*, WITH VERTICAL ROWS OF BARK PATTERNS, AND *Lepidodendrons*, WITH DIAMOND-SHAPED BARK PATTERNS. AT THE UPPER LEFT CORNER ARE SEEN THE CONE-BEARING BRANCHES OF *Lepidodendron*. AT THE RIGHT ARE HUGE, JOINT-STEMMED *Calamites* RUSHES.



Geological Survey of Canada

FIG. 2. A FOSSIL TREE TRUNK IN A COAL FIELD OF NOVA SCOTIA.

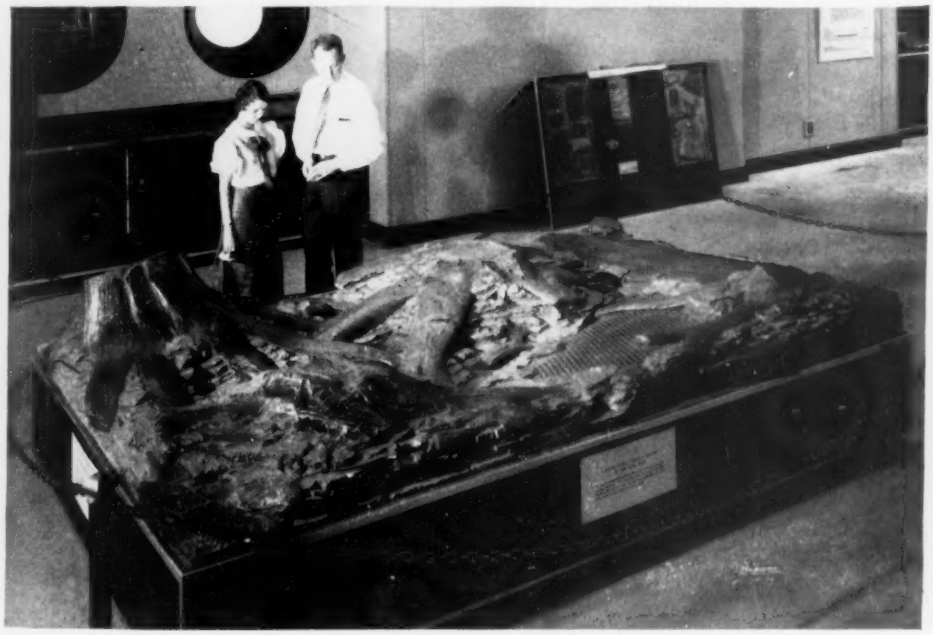
HERE AN ENTIRE FOREST WAS FLOODED BY THE SEA, BURYING THE TREES UNDER DEEP SEDIMENTS AND PRESERVING THEM AS COAL AND FOSSILS.

particularly the new family of "sulfa" drugs—miracle drugs for the prevention of infection and the curing of diseases. The wonders which these drugs performed upon the wounded at Pearl Harbor is an epic which will long live in the annals of modern medicine.

The importance of coal in our modern civilization caused the eyes of science to be directed toward the manner of its origin. It has long been recognized that coal consists of the metamorphosed remains of plants that lived in past ages. It has been established, too, that these plants grew in great swamp forests of luxurious tropical vegetation, covering vast areas of the earth's surface (Fig. 1). Strangely, most of these ancient tropical coal forests seem to have grown in latitudes which to-day have temperate, sub-arctic and arctic climates. Over half of the world's known deposits occur within the boundaries of the United States. Europe and Asia, too, have large supplies. It is more puzzling, however, to account for the vast deposits in Alaska, Siberia, Greenland and Antarctica, great areas of which are perpetually covered with ice and snow.

But the scientist is not content to accept these facts merely as so much information. Knowledge once gained is an ever-continuing incentive toward the accumulation of further knowledge. It is desirable to know what sort of plants comprised those ancient forests and how they were able to grow luxuriously in regions which to-day support such vastly different kinds of vegetation or practically none at all.

Coal has been deposited in various quantities ever since land plants began to flourish upon the earth. But the most important of these coal beds were formed



Museum of Science and Industry, Chicago

FIG. 3. THE PLANT ORIGIN OF COAL

VIVIDLY DISPLAYED BY THIS EXHIBIT AT THE MUSEUM OF SCIENCE AND INDUSTRY IN CHICAGO. AN ENTIRE SECTION OF A STRATUM OVERLYING A COAL BED IN SOUTHERN ILLINOIS HAS BEEN EXCAVATED TO SHOW ITS CONTENTS OF FOSSIL TREE STUMPS, STEMS AND LEAVES.

FIG. 4. HUGE ELECTRIC SHOVELS OPERATING IN MODERN STRIP MINES, INVITE THE FOSSIL COLLECTOR TO FOLLOW IN THEIR WAKE. IN THESE STRATA ARE FOUND THE PLANT REMAINS OF ANCIENT, TROPICAL FORESTS.

during the Carboniferous period of the earth's history or, more specifically, during the Pennsylvanian subdivision of this period. The Pennsylvanian period began about a quarter of a billion years ago and lasted for thirty-five million years. Throughout this long period of time, the sun's rays showered down the energy which became entombed in our wide-spread coal fields, providing the material for a more abundant life to-day.

George Langford

FIG. 5. ROOT OF A COAL AGE TREE. KNOWN AS *Stigmaria* AND ONCE THOUGHT TO BE THE STEM OF A PECULIAR TREE. SUCH FOSSILS ARE NOW KNOWN TO REPRESENT ROOT SECTIONS OF VARIOUS KINDS OF TREES. THE ROUND SCARS ARE ATTACHMENT PLACES OF FORMER ROOTLETS.

Because coal is a sedimentary rock having its origin in the plant life of another age, it follows that the study of coal should tell us much about the kinds of plants which formed it. However, the plant remains constituting the actual coal itself usually have been so squeezed and altered that their details are only partially recognizable. To a certain extent, the cell structure and reproductive spores of these ancient plants can be studied in thin sections of coal under the microscope. On the other hand, the remains which exist as fossils in the strata immediately above or below the coal beds are often so well preserved that complete leaves, with their intricate veins and texture, can be seen and studied.

The underlying beds of shale represent the former soil in which these plants grew. Commonly their roots, and sometimes upright trunks, are preserved just as they existed in the ancient soils (Fig. 2). The strata overlying the coal beds represent the sediments which were deposited above the plants during times of flood, killing and burying them, but preserving their remains as coal and fossils (Fig. 3). In these shale layers the individual plant parts have been more or less isolated and enclosed by protecting deposits of sediment. When excavated, the shaly layers reveal the entombed fossils in a perfect state of preservation.

In northeastern Illinois, particularly in the area southwest of Joliet, a coal seam lies close to the surface, and peculiar conditions of mineralization have preserved the fossils in an unusual state. Here the shale immediately surrounding

each individual fossil has become harder than the general mass of sediments, forming rounded or egg-shaped nodules or concretions. When given a violent blow with the hammer, these nodules readily split into two halves, revealing the enclosed fossil which formed a natural line of weakness through the stone. These concretions vary in size from a fraction of an inch to a foot or more in length. Usually a complete unit of a plant is exposed to view when a concretion is split open.

The usual method of obtaining such fossils is by collecting these concretions from the shale heaps following coal-mining operations. The comparatively new method of "strip" mining has resulted in the accumulation of vast heaps of such nodule-containing shale over wide areas in the mining districts. The mining itself is done by means of enormous electric shovels (Fig. 4). First the shale, averaging from twenty to sixty feet in depth, is scooped away from over the coal bed, exposing it to view. The coal is then scooped up and loaded into railway cars. The shale, which is shoveled aside in high piles, contains the fossiliferous concretions. Having thus been loosened from the general mass of sediments, the concretions are gathered from the dump heaps by the geologist who cracks them open and examines them for fossil contents. Because of this unusual occurrence of fossils here, this area, known as the Mazon Creek region of Illinois, has been more thoroughly studied for coal plant fossils than any other area of such limited extent in the world.

When dealing with living plants, the scientist can study all their parts together; but when working with fossils, it is very unusual to find complete plants. The stems, roots, leaves and reproductive organs are generally isolated and separated from each other. Since it is sometimes impossible to piece these parts together and arrive at a reconstruction of the whole, the practice has necessarily arisen of giving distinct generic names to the various plant parts. Thus organs with different names may really have belonged to the same plant. Similarly, a genus may also include remains which appear identical, but actually belonged to different plants. For example, the genus *Stigmaria* was established early in the nineteenth century by the French paleobotanist, Brongniart, for a commonly occurring stem-like fossil characterized by numerous rounded scars upon its surface (Fig. 5). He presumed that the fossil represented the stem of a distinct type of tree and that the scars marked the attachment places of fallen leaves. It was not until the latter part of the century that specimens were discovered which revealed that *Stigmaria* was not the stem of a distinct tree at all, but actually was the root of various

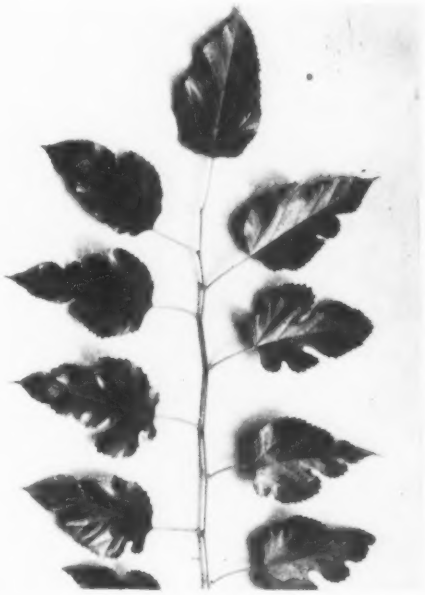
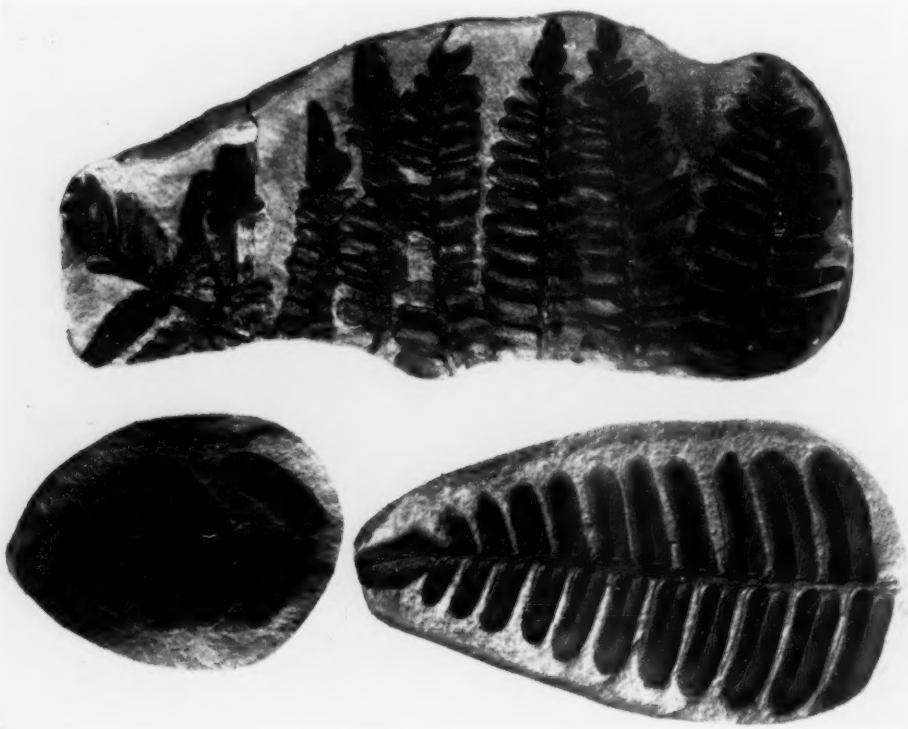


FIG. 6. COMMON MULBERRY TWIG
CARRYING LEAVES OF DIVERSIFIED SHAPES, ILLUSTRATES THE PROBLEMS OF THE PALEOBOTANIST WHO ATTEMPTS TO RECONSTRUCT AND CLASSIFY PREHISTORIC PLANTS FROM THE WIDELY SCATTERED FRAGMENTS FOUND IN ANCIENT STRATA.



George Langford

FIG. 7. TAXONOMY PROBLEMS ARE SHOWN IN THESE SEED-FERN FOSSILS FROM MAZON CREEK, ILLINOIS. *Neuropteris flexuosa* (LOWER LEFT) IS CHARACTERIZED BY A RELATIVELY LARGE TERMINAL LEAFLET. *Neuropteris gigantea* (LOWER RIGHT) HAS A RELATIVELY SMALL TERMINAL LEAFLET. OTHER CHARACTERISTICS OF THE TWO FORMS ARE SIMILAR. FOR MORE THAN A CENTURY, THESE TWO COMMON COAL AGE FORMS HAVE BEEN RECOGNIZED AS DISTINCT SPECIES. THE LARGE SPECIMEN AT THE TOP, WHICH SHOWS A PORTION OF AN ENTIRE FROND, WAS ONLY RECENTLY DISCOVERED. TENTATIVELY NAMED *Neuropteris flexuosa*, IT INDICATES THAT THE TWO PREVIOUSLY KNOWN SPECIES MAY HAVE BELONGED TO THE SAME PLANT.

genera of trees. Its surface scars marked the location of former rootlets, and not leaves, as originally thought.

An interesting analogy exists in the living mulberry which may bear as many as a half dozen varied forms of leaves upon the same twig (Fig. 6). If such leaves were found separately as fossils, they might well be considered as different species, and only the finding of an entire stem with the several leaf forms attached would establish them as actually belonging to the same plant.

As the study of fossil plants continues, rare specimens are discovered from time to time which settle such pertinent points. In many respects, the work of the paleobotanist is thus made all the more fascinating, for he never knows when the blow of his hammer may uncover a specimen which will settle a century-old problem or reveal a new type which has never before been seen by human eyes (Fig. 7). Thus new light is constantly being shed upon the course which plants have followed in their evolution from the lower forms of the past to the more complex forms of the present.

When we survey all that is known of the geological history of our earth, it is difficult to realize that comparatively little was known on this subject more

than a few generations ago. Geology, as a science, had not yet come into existence; and its subdivision, paleobotany, is much younger. The foundations of scientific paleobotany were laid in Germany in 1801 by Ernst Fredrich, Baron von Schlotheim. Although the occurrence of petrified wood and leaf impressions had been noted by a few earlier writers, Schlotheim's works are the earliest scientific records known in paleobotany. His work was followed by that of Sternberg, Brongniart, Lindley, Hutton, Goeppert and Schimper, all of whom were Europeans, whose studies of plant fossils were published between 1820 and 1884.

The earliest known plant fossils from America were obtained by Ebenezer Granger in 1821 from the coal fields of Ohio. The first work of consequence to be accomplished in North American paleobotany was done in Nova Scotia by Sir William Dawson, beginning in 1845. Contemporaneously, work was done in the United States by Leo Lesquereux, a native of Switzerland, who had emigrated to America. After his arrival here, he became associated as a paleobotanist with numerous state and territorial geological surveys which were then being organized from time to time. Most prominent among his works were the studies of the coal flora of Pennsylvania and Illinois, the results of which appeared between 1858 and 1880. His work was followed by that of David White, late of the U. S. Geological Survey, whose publications on the coal flora of Missouri, issued between 1893 and 1899, are particularly noteworthy.

These foundations in paleobotany have been intensely broadened since the turn of the present century by recent paleobotanists. As a result, knowledge of the ancient vegetation which clothed our

FIG. 8. BARK PATTERN OF *Lepidodendron* WITH CHARACTERISTIC DIAMOND-SHAPED SCARS LEFT BY FALLEN LEAVES. THESE SCARS CONTINUED TO GROW DURING THE LIFE OF THE TREE, EVEN THOUGH THE LEAVES THEMSELVES HAD FALLEN.

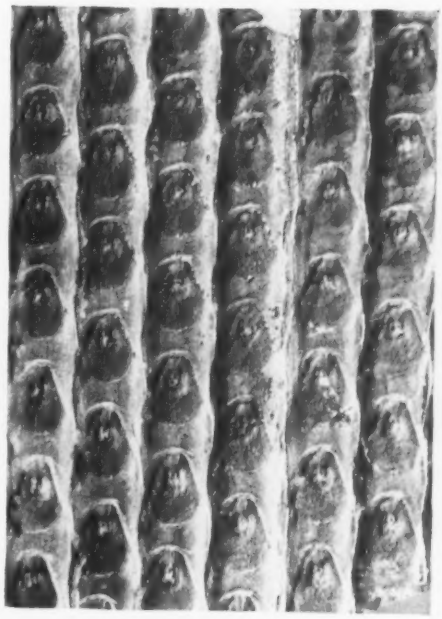


FIG. 9. BARK PATTERN OF *Sigillaria* IS CHARACTERIZED BY LONGITUDINAL ROWS OF OVAL-HEXAGONAL SCARS, MARKING THE FORMER POSITIONS OF FALLEN LEAVES.

Field Museum of Natural History

FIG. 10. A *SIGILLARIA* TREE

AS RECONSTRUCTED AT THE FIELD MUSEUM. THESE CLUB-MOSSES ATTAINED HEIGHTS OF MORE THAN 100 FEET, OFTEN SIX FEET IN DIAMETER.

earth during the great coal age has become amazingly complete.

Reconstructions of the coal age landscape show us scenes that were vastly different from those of to-day. There were no woodlands of deciduous, broad-leaved trees nor waving, grassy prairies. No pine trees clothed the hillsides, and no brightly hued flowers added color to the forests. Such plants as these were not destined to make their appearance until millions of years later. Instead, vast swamplands covered much of the earth's surface, in which flourished species of trees and plants which have long since become extinct.

The plant life, although very abundant consisted entirely of lower plant orders, such as are represented to-day by club-mosses, horsetails and ferns. Although being lower forms botanically, many of them were giants in size. The coal forests were dominated by great pteridophytes and primitive gymnosperms which attained the dimensions of our larger present-day trees. The undergrowth consisted mostly of ferns and other plants which bore fern-like foliage.

The principal trees of the coal age forests were members of the order *Lycopodiales*. This order, during the coal age, included a much larger, more numerous and more highly differentiated variety of forms than it does to-day. The majority of living members are found as small terrestrial plants or as epiphytes in moist tropical regions. A few species, found in temperate regions, are represented by the genera *Selaginella*, a club-moss, and *Lycopodium*, a diminutive ground-pine used in the making of Christmas decorations.

During the coal age, however, the lycopods were mostly arborescent forms equal to, or exceeding in size, the average forest trees of to-day. Dominant among them were the *Lepidodendron* trees, characterized by diamond-shaped, spirally arranged scars on their trunks (Fig. 8), and the *Sigillaria* trees, with vertical rows of oval scars (Fig. 9). These unusual scar patterns represent the points of attachment of fallen leaves. A peculiar characteristic of this tree bark was the continued growth of the leaf scars, even though the leaves had long since fallen off. The leaves were long and grass-like in appearance and

were clustered around the growing tips of the stems. As the stems grew, new leaves appeared at the tips, and the lower leaves fell off.

The *Lepidodendrons* branched dichotomously, that is, by twos—each branch dividing into two smaller ones again and again to the ultimate tips. At the tips were the reproductive organs or spore-bearing cones (Fig. 1). These cones were shed at intervals when ripe, the branches then dichotomized at this point, forming two new branchlets, at the tips of which a new series of cones developed. It is believed that fertilization took place upon the damp, swampy ground.

The *Sigillaria* trees seldom branched. Usually they bore their leaves in a single, spreading crown, much after the fashion of modern palm trees (Fig. 10). Their cones were produced on small stems which emerged directly from the trunks in a manner somewhat similar to the pod-bearing structures of present-day *cacao* trees.

The lycopod trees attained heights of a hundred feet or more, with diameters up to six feet. They were extremely abundant, had a world-wide distribution, and constituted an important element in the formation of coal. Some coals, such as cannel coals, seem to be

Field Museum of Natural History

FIG. 11. SMALL *CORDAITES* TREE

AS RECONSTRUCTED AT THE FIELD MUSEUM. THESE TREES, CHARACTERIZED BY LARGE, STRAP-LIKE LEAVES, AND BEARING SMALL WINGED SEEDS, WERE EARLY MEMBERS OF THE *Gymnosperm* ORDER WHICH INCLUDES THE MODERN PINE TREE.

Field Museum of Natural History

FIG. 12. A FOSSIL BRANCH OF *CALAMITES*

SHOWING WHORLS OF SPATULATE LEAVES ARRANGED ALONG THE STEMS OF THESE GIANT RUSHES.

made up largely of the spores of these trees.

In addition to the various forms of lycopod trees, the coal age landscape contained gymnospermous trees of the higher order, *Cordaitales* (Fig. 11). These trees were less common than the lycopods, but nevertheless were widely distributed. In some foreign regions, they seem to have constituted locally the dominant tree growth. Individuals attained, or even exceeded, heights of a hundred feet, but did not exceed diameters of two feet. The *Cordaites* trees branched much in the fashion of modern trees, but bore large, strap-like leaves, spirally arranged around the stems. The reproductive organs consisted of male and female catkins borne on the branches. The female, or ovulate, catkins produced round, flattened and frequently winged, seeds somewhat resembling those of present-day elms and maples. It is believed that these trees grew in the highlands, away from the coal swamps proper. Inferences in this respect are taken from the fact that *Cordaites* leaves are found widely scattered, suggesting that they may have drifted down the streams to become buried and preserved, while the tree

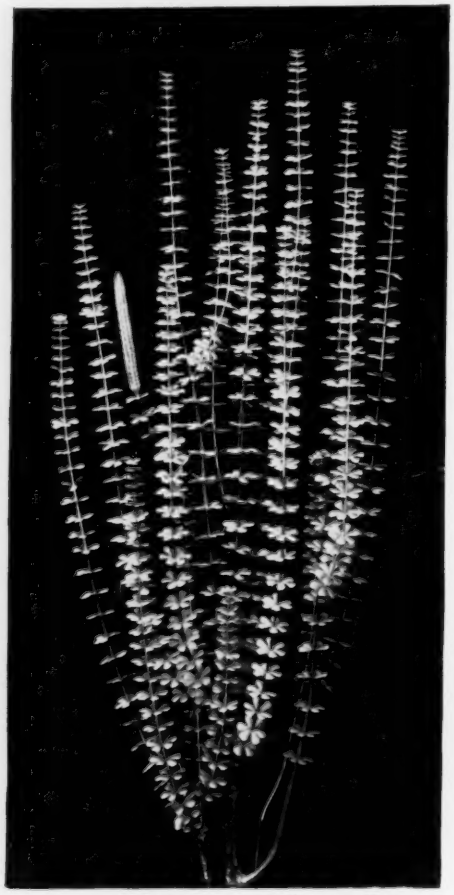


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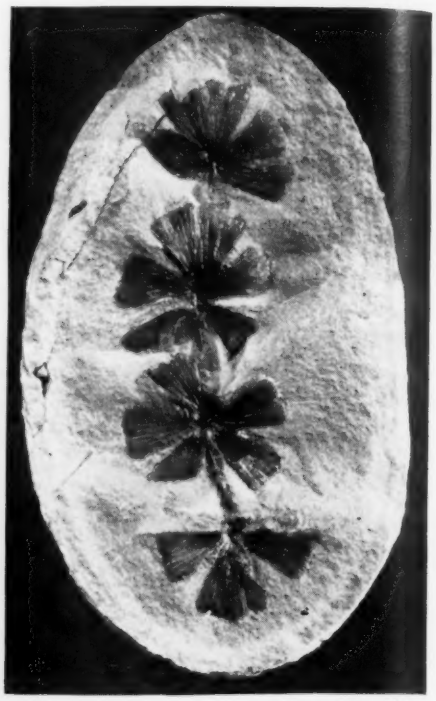
FIG. 13. A SMALL HERB (*Sphenophyllum*) OF THE COAL AGE, AS RECONSTRUCTED AT THE FIELD MUSEUM. GROWING ABOUT TWO FEET HIGH, THIS PLANT FURNISHED MUCH UNDERGROWTH IN CARBONIFEROUS FORESTS.



George Langford

FIG. 14. AMAZON CREEK NODULE CONTAINING A PORTION OF THE STEM OF *Sphenophyllum*. IN LIFE, THIS SPECIES CONTAINED SIX WEDGE-SHAPED LEAVES IN EACH WHORL.

trunks, which are quite rare as fossils, may have died and decayed on the uplands.

The banks of the ponds, lakes and watercourses of the ancient lowland forests were lined with dense growths of gigantic rushes, called *Calamites* (Figs. 1 and 12). They commonly attained heights of fifty feet, equalling the modern bamboo in size. The stems were jointed at intervals along their lengths, some types bearing lateral branches at all these joints, and others having branches only at widely separated joints. The leaves were borne in whorls entirely around the stems, and in groups of six to twenty or more. The reproductive spores were borne in cones at the tips of the stems. Although the gigantic *Calamites* have long since become extinct, they are represented to-day by a small descendant, *Equisetum*, commonly known as the horsetail, scouring-rush or jointed-grass, which grows as a weed in moist localities and roadside ditches. The growth of secondary wood in the trunks of the ancient *Calamites* enabled them to become sturdy, tree-like forms very different from the modern *Equisetum*, which has no secondary thickening.

Growing amid the gigantic forms of the coal age forests was a small, herbaceous plant, called *Sphenophyllum* (Figs. 13 and 14). This plant, which seldom exceeded two feet, had a slender, branching stem bearing whorls of wedge-shaped leaves. In appearance, it resembled somewhat the modern bedstraw or goose-grass (*Galium aparine*), but actually the two have no relationship. The leaves of *Sphenophyllum* were attached around the stems in multiples of three, with six, nine or twelve being the average number per whorl in most species. The reproductive spores were borne in cones at the tips of the branches and were similar in general aspect to those of the much larger *Calamites*.

Fossil impressions of fern leaves in the strata of the coal age are scarcely distinguishable in appearance from the finely divided fronds of modern ferns. Until quite recently these plants were all re-

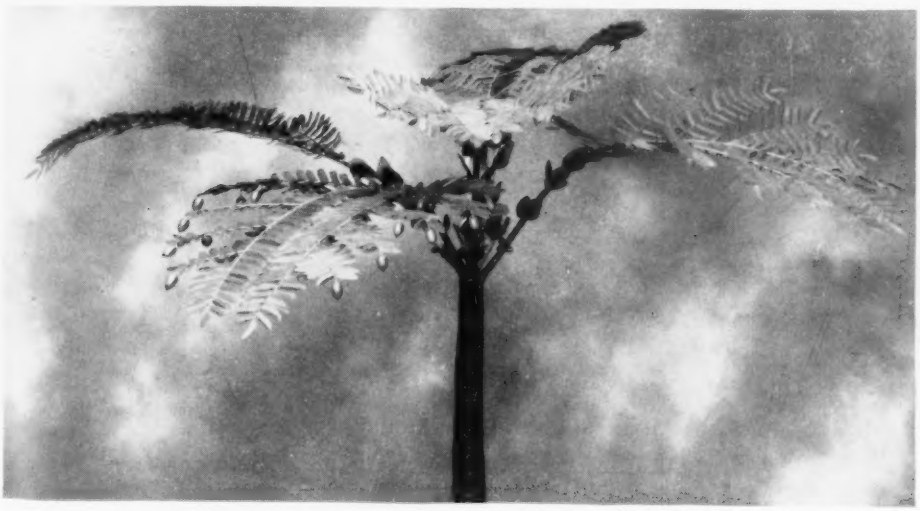


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FIG. 15. RECONSTRUCTION OF A SEED-FERN.

THE NUT-LIKE SEEDS WERE USUALLY BORNE AT THE TIPS OF THE LEAF SEGMENTS, BUT OCCASIONALLY THEY WERE AT OTHER POINTS ALONG THE RACHIS.

garded as true ferns. Because of their abundance, the coal period was commonly called the Age of Ferns.

Modern research, however, has shown that the stem structure of many of these so-called ferns differed from that of any living ferns, and, more recently, fossils have been found showing seeds attached to the fronds. This is in marked contrast to all present-day ferns, which re-

Field Museum of Natural History

FIG. 16. SMALL TRUE TREE-FERN AS RECONSTRUCTED AT THE FIELD MUSEUM. SUCH TREE-FERNS WERE QUITE SIMILAR TO THOSE OF PRESENT-DAY TROPICAL REGIONS.

produce by means of spores borne on the under sides of the leaflets. These fossil plants have therefore been placed in a distinct order, called *Cycadofilicales* by American paleobotanists and *Pteridospermeae* in Europe. Popularly, they are simply called seed-ferns (Fig. 15).

Some of these coal age plants were true ferns, however, but they occupied a subordinate position to the seed-ferns and can not be distinguished from them except when the reproductive organs or sufficiently preserved stem structure is found in association with the leaves. Both groups included herbaceous forms with habits similar to modern ferns. Other forms were scramblers or vines, and still others were trees reaching heights of seventy feet and trunk diameters of two feet or more (Fig. 16). These tree ferns were not vastly different from those of our present-day tropics, except that some were larger and some bore seeds. The seed-ferns became extinct shortly after the close of the coal age, but true ferns have continued to live through all the succeeding changes of the earth's geologic history down to the present time.

Many species of fern-like leaves, occurring as fossils, can not be placed, as yet, in their correct botanical positions because reproductive organs or stems with diagnostic features have not been found in association with them. Hence it is not known whether many of them were true ferns or seed-ferns.

Many kinds of nut-like seeds are found in the coal age strata (Figs. 17 to 19). They usually occur detached, but it is now known that they belonged to the seed-ferns. Very few, however, have actually been found attached to the fern fronds; hence, only in exceptional cases is it known to what species of seed-fern particular seeds belonged. Seeds attached to identifiable stems or leaves are so rare that the finding of such a specimen is usually of considerable scientific importance. Such specimens found by laymen should be immediately turned over to specialists in this field for detailed study.

The story told by plant fossils adds an important bit to our knowledge of the earth's long, eventful history. Plants now insignificant and few in number, such as the ground-pine, are found to

be the descendants of a long line of stately ancestors which formed the dominant growth of primeval forests. Others, like the seed-ferns, have left no descendants whatever. Still others, the true ferns, were able to hold their own through the succeeding ages and have come down to us in an unbroken line. Although numerous attempts have been made to explain such riddles, we can only speculate vaguely, as yet, upon the causes of success or failure which have determined such events.

The flora of the great coal age compares more approximately with that of our present tropics than with any other. The trees of the Carboniferous period do not exhibit annual growth rings in their stems, and this also is an indication of more or less uniform growing conditions uninterrupted by seasonal fluctuations. This situation excites the interest of scientists because the greatest coal deposits are situated in the northern hemisphere and within the temperate and arctic zones. From this evidence it would seem that a warm, uniform climate must have then existed over nearly all the earth's surface.

George Langford

FIG. 18. ANOTHER NUT-LIKE SEED (*Holcospermum*) BORNE BY CERTAIN SEED-FERNS, HAD NUMEROUS LONGITUDINAL RIBS AND GROOVES ON ITS HUSK. THIS EXTERIOR HUSK WAS ABOUT TWO INCHES LONG; THE ENCLOSED NUT ITSELF BEING FROM ONE-HALF TO ONE INCH LONG.

Illinois State Geological Survey

FIG. 17. A FOSSIL SEED OF THE TYPE BORNE BY THE SEED-FERN SHOWN IN FIG. 15. SUCH SEEDS, CLASSIFIED UNDER THE GENERIC NAME, *Trigonocarpus*, VARIED IN LENGTH FROM THREE QUARTERS OF AN INCH TO TWO INCHES. THE SHELL WAS DIVIDED LONGITUDINALLY INTO THREE EQUAL VALVES, MARKED BY PROMINENT RIDGES AT THE SUTURE LINES.

Such a condition would very well account for the finding of plant fossils and coal beds in the arctic and antarctic regions. Unfortunately, however, the problem is not so easily answered. In addition to a favorable climate, plants also require an abundance of sunlight for luxuriant growth. The explanation has failed to show how the coal-forming plants could have received sufficient sunshine to have grown continuously, without showing even an indication of

FIG. 19. FOSSIL SEED

Carpolithus noći, JUST RECENTLY DISCOVERED, HAS NUMEROUS BLUNT, IRREGULAR SPINES UPON ITS SURFACE. ALTHOUGH ITS AFFINITY IS NOT YET KNOWN, IT IS PROBABLY THE FRUIT OF A SPECIES OF SEED-FERN.

seasonal growth rings, in latitudes where the polar nights are several months long.

An attempt to explain this riddle was made a few years ago by the German scientist, Alfred Wegener, and has been further advanced by a few other scientists. This theory, called the Continental Drift Theory, suggests that the continents were once part of a single larger continent which existed in more central latitudes where luxuriant plant life was possible. The great continent is represented as having floated on a plastic substratum. Then, at a more recent time, this hypothetical continent broke into several sections which drifted apart to become the separate continents and land masses as we know them to-day.

This theory, which radically opposes previous conceptions of the stability of continental masses, has not met with a uniformly favorable reception among geologists. However, nothing else so well explains the wide distribution of the tropical vegetation of the great coal age. Only time and continued research will ultimately tell whether or not the theory has practical merit.

Unfortunately, the world is now engaged in a mighty conflict, and many of the scientists who have been engaged with the solutions of such problems have been called to more immediate and urgent research. But eventually, in a free world, there shall again be ample opportunity for the consideration of such age-old problems. Although frequently interrupted and delayed, the work of the scientist is never finished—for he never knows when some bit of evidence, newly discovered or previously considered unimportant, may furnish the clue to a more thorough understanding of the profound changes which have affected our earth and the evolution of life upon it.

ANCIENT IRRIGATION IN CHINA BROUGHT UP TO DATE

By Dr. W. C. LOWDERMILK and Dr. D. R. WICKES

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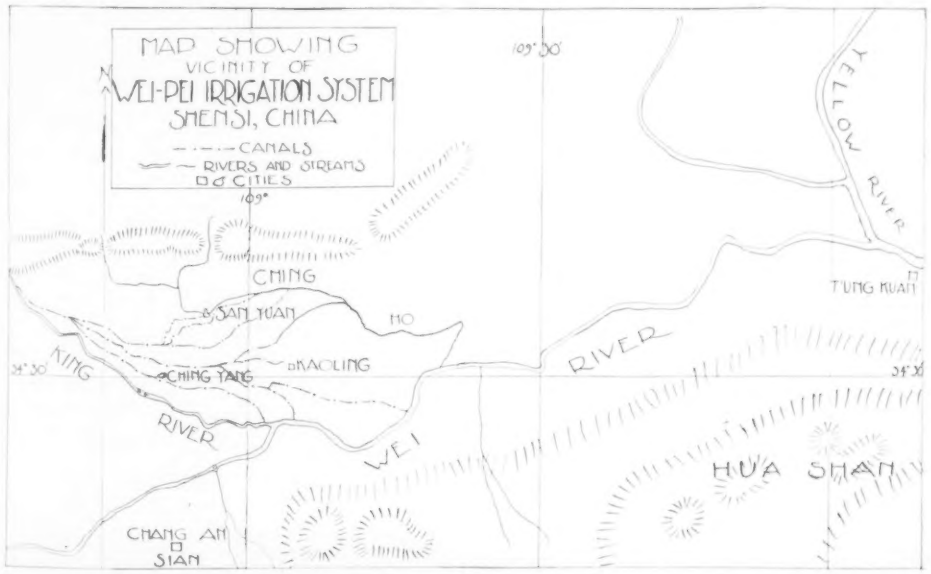
Of irrigation works constructed in China with the consultation of American engineers, the most interesting project has recently been brought to completion in the alluvial plain of the Wei River. This project was under study by Mr. Li Hsieh, a Chinese conservancy engineer, who showed O. J. Todd, chief engineer of the International Famine Relief Commission, and the senior writer over the project several years ago. Since that time, the Chinese Government has completed this project, to use the available flow of the King River to its maximum capacity for irrigating land in the Wei-Pei plain.[1]

[1] O. J. Todd, *Civil Engineering*, 7: 553, August, 1937. Mr. Todd was chief engineer and Mr. Eliassen resident engineer for the intake works and upper portion of the main canal, Mr. Li Hsieh chief engineer for the rest of the project. A fuller description by S. Eliassen and O. J. Todd was published in the *China Journal*, 17: 170–180, October, 1932.

The Wei River is the principal tributary of the Yellow River, which has so long been known to the Sons of Han as "China's Sorrow." The Wei drains the northern slopes of the picturesque Tsingling range of mountains. This range, lying east-west athwart the country, is the natural great wall of China; it separates the regions of the loess to the north from regions without loess in the south and divides wheat-growing from the rice-growing areas of China. The Wei River irrigation project is one of the earliest recorded in Chinese history and has a fascinating history.

The fruitfulness of the fertile plain of the Wei River under ancient works of irrigation, which were begun more than 2,000 years ago, nourished in former times a rapidly growing population of vigorous people who established the ancient capital of Changan (Prolonged Peace). The present city of Sian in Free

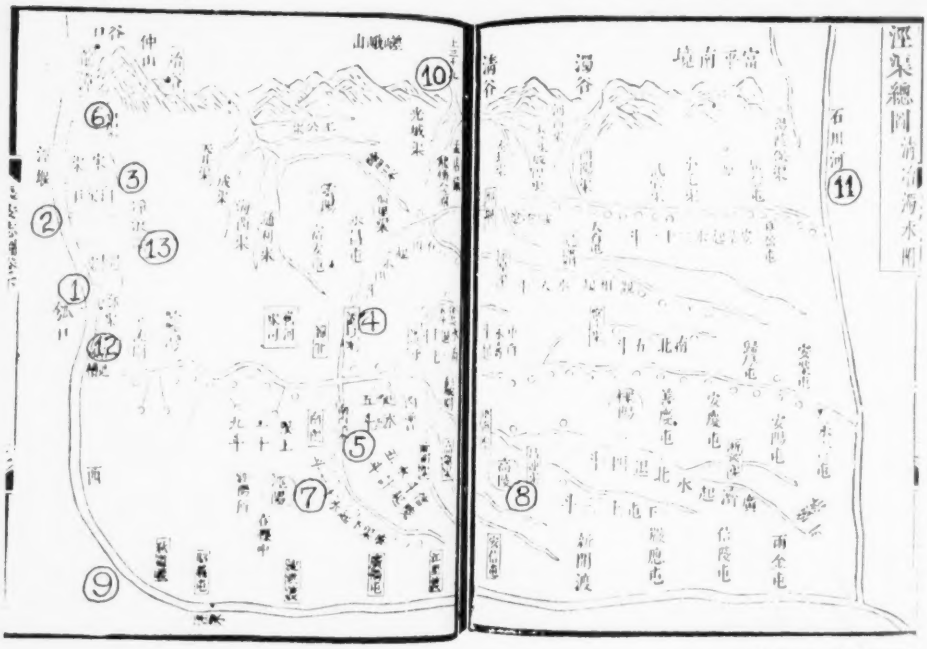


A MAP OF THE VICINITY OF THE WEI-PEI IRRIGATION SYSTEM

China now stands on the site of this ancient capital of the Chinese Empire. A paper on the Yellow River problem, by O. J. Todd, consulting engineer, and S. Eliassen, has just appeared in the *Transactions* of the American Society of Civil Engineers[2] which refers to the irrigation works recently completed to spread water again on lands where ancient works of irrigation had failed. Because the Chinese gazetteer and other records of this irrigation project go back more than 2,000 years, the detailed history of dealing with silt-laden waters has a lively interest to American conservationists, who are concerned with flood control and water supply in the new land of America. Such a long authentic record gives a background to our forecasting and preparing for problems of silt control and disposition. The junior author has consulted the splendid library in the Chinese language which has been collected in the Library of Congress and has translated these records going back more than 2,000 years. From field surveys of the Wei-Pei project and from these accounts is drawn the material for this paper.

The history of the valley of the Wei River and its irrigation is to be found scattered in numerous Chinese works, of which some go back to the early years of the Christian era, and others were written at intervals by Chinese historians down to the present time. A study of this literature reveals a fascinating story of great efforts made at many different times to maintain a large and vigorous population in this region of what is now "Free China."

[2] Vol. 105, p. 346, 1940.



Library of Congress

OLD CHINESE MAP FROM GAZETTEER OF CH'ANG-AN DATED IN 1784

SHOWING CANALS FROM THE KING RIVER, WITH CANALS FROM SMALLER STREAMS IN NORTHERN PART. (1) INTAKE OF CHENG CANAL (THE EARLIEST RECORDED); (2) INTAKE OF PAI CANAL (THE SECOND RECORDED); (3) SUNG DYNASTY CANAL; (4) AND (5) GREAT PAI AND SOUTH PAI CANALS; (6) ROCK-CUT CANAL; (7) CHING YANG CITY; (8) KAO LING CITY; (9) KING RIVER; (10) CH'ING VALLEY; (11) SHIH CH'UAN HO RIVER; (12) ANCIENT OVERFLOW CHANNEL; (13) OVERFLOW CANAL.

SITE OF THE ORIGINAL INTAKE OF THE CHENG CANAL

BUILT IN 246 B.C. THE ENTRENCHED CHANNEL OF THE KING RIVER IS SEEN IN THE BACKGROUND. THE STREAM IS NOW ABOUT SIXTY FEET BELOW THE ORIGINAL CANAL LEVEL.*

The first recorded canal for the irrigation of this area was begun under the first Emperor of China, Ch'in Shih Huang, in his first year as King of Ch'in, 246 B.C., a few years before he became Emperor.[3] The area is a broad plain of alluvium and loess which was deposited in an ancient lake basin by water and by wind. The Wei River with a few tributaries, of which the King River is the principal one, flows through this "Cradle of Chinese civilization." The Wei-Pei irrigation project has been eleven times remade in whole or in part during the twenty centuries since that time. In addition, repairs and additions were made from time to time. All this tells of a remarkable struggle to maintain productiveness of land irrigated with silt-laden waters. It is a battle with silt for twenty centuries which was finally lost until modern power machinery and reinforced concrete construction gave a new lease on life to this famous irrigation project. Even now the total area irrigated under modern works is less than that once watered under ancient works.[4]

This age-old irrigation system has played an important role in the history of China. For centuries it made the region in which it lay the key economic area of China, supporting a population that was able to control the rest of the country.[5] As the old record puts it: "Thereupon Kuanchung became fertile territory without bad years; whereupon Ch'in became rich and powerful and finally conquered the feudal princes."[6]

It is recorded that in the early period

[3] Ch'ao-ting Chi, "Key Economic Areas in Chinese History," 1936, p. 75 *ff.*

* Photographs by O. T. Todd and senior author.

[4] 100,000 acres in 1937. O. J. Todd, *Civil Engineering*, 7: 553, August, 1937. Over 40,000 ch'ing, more than 400,000 acres at 10 mou to the acre, for the first canal system according to the Han Shu and Shih Chi historical records. *Cf.* Edouard Chavannes, "Les Memoires Historiques de Se-Ma Ts'ien, pp. 523 *ff.*, 1898. For the size of the mou in the Ch'in and Han Dynasties see Mabel Ping-Hua Lee, "The Economic History of China," p. 435, New York, 1921.

[5] Chi, 1936, pp. 77–80, 95.

[6] Ch'ien Han Shu, 29/5 b *ff.*

the system irrigated about 625 square miles, or 400,000 acres,[7] of salty alluvial plain to produce crops of millions of bushels of grain. Harvests of 14,500,000 bushels are reckoned as produced on the land irrigated by the first canal system alone. The average yield was about 36 bushels of wheat per acre.[8]

The maintenance of such a system was an immense task, and many and varied methods were used in the course of the two thousand and more years since it was begun. It may be inferred that removal of silt was an early and constant task, though the earliest specific mention of the necessity for this is found in a report of the year A.D. 995.[9] This report mentions the blocking of canals with silt as a thing to be yearly watched for and promptly attended to by officials in charge. Before this time the presence of silt in considerable quantities in the water used for irrigation seems to have been regarded as an advantage rather than a disadvantage by improving fertility of fields. Such an idea is expressed during a period between A.D. 649 and 659 by an official of the Emperor Kao-tsung of the T'ang dynasty.[10] An ancient Chinese song in celebration of the early canals, recorded in the history of the earlier Han dynasty[11] in A.D. 82, has the same idea. "In one stone of King water, there are several pecks of mud. Both irrigating and fertilizing, it makes long our growing millet, feeding and clothing the capital's vast multitudes."

Change in the appraisal of the value or nuisance of silt in irrigation water is also found in other projects outside of

[7] 40,000 ch'ing, see note 4.

[8] The Han Shu states that the 40,000 ch'ing of salt land when irrigated produced throughout harvests of one chung (about 3.626 bushels) per mou. *Loc. cit.*

[9] Official report quoted in History of the Sung Dynasty (Sung-Shih) 94/24 b.

[10] Quoted by K'ung Chuan, official A.D. 1131-1162, in Pai K'ung liu t'ieh 81/5b *f.* Quoted from this in Shensi T'ung chih (official gazetteer) (1735) 39/64 a.

[11] Ch'ien Han Shu, 29/12 a.*f.*

DRY CANAL OF THE WEI-PEI IRRIGATION SYSTEM

SHOWING EXCELLENT MASONRY AT HEAD WORKS OF SUBDIVISION CANALS. A BURIAL MOUND IS VISIBLE IN LEFT MIDDLE GROUND; A TEMPLE, WITH A GROVE OF TREES IN RATHER BAD CONDITION OWING TO GENERAL POVERTY OF THE REGION, MAY BE SEEN IN THE BACKGROUND; THE SENIOR WRITER STANDS BY THE CANAL.

SECTION OF THE CANAL CUT THROUGH LIMESTONE ROCK

CARRYING ONLY THE CLEAR FLOW OF GREAT SPRINGS ISSUING FROM LIMESTONE CAVERNS CUT THROUGH IN DIGGING THE CENSOR WANG CANAL IN 1314–1318 A.D., PART OF THE WEI-PEI PROJECT.

China. So long as silt consists of top soil eroded from slopes of a drainage, deposition of it on valley lands generally enhances their fertility; but when silt is derived from subsoils and sterile substrata of soils by erosion it damages land. The spread of clays upon fields in the Rio Grande Valley in the vicinity of Albuquerque[12] has done serious damage to the land. Likewise, when the material is made up of coarse sands, productivity of irrigated land may be seriously lowered, as in the Imperial Valley. In addition to its harmful effects, sterile material encumbers a project by the necessity of its removal, always at increasing costs, and in time endangers the project as the Wei-Pei Project discloses.

A report to the throne in 1343 by Sung Ping-liang[13] recommends a method used in ancient times, the closing of flood gates in time of unusually high water in the King in order to prevent the silting up of the canal. He calculated that by rebuilding such gates to be opened and closed at proper times to prevent suspended mud from entering the main canal they would decrease by half the labor of cleaning silt out of canals.

The *Gazetteer* of Chang-an for 1787[14] says: "Every year repairs are added, and the labor of men cleaning out mud and sand from the rock-cut canal, above and below, does not cease." Each family using water on its land had also every year to open and clean out canals and ditches to assure a free and uninterrupted flow.[15] Piles of silt thirty-five feet high along the banks were reported in the fourteenth century, and passageways were repeatedly excavated through these that the silt taken from the canals might be moved farther from the banks rather than placed on these mountainous piles from which it was liable to erode or slip back into the water during heavy rains.[16]

[12] H. H. Bennett, *Jour. Am. Soc. Agr.*, 23: 1, June, 1931.

[13] Censor in charge of Shensi circuits. Chang-an chih Atlas, hsia/19a. *f.*

[14] Chang-an chih (1787) (1891 reprint) Atlas hsia/ 9 b.

[15] *Id.*, hsia/12 a.

[16] *Id.*/20 a; Yuan Shih 66/15 a; Ching-yang hsien chih, (1841) 13/3 b.

A SECTION OF THE CANAL

THROUGH WHICH FLOWS CLEAR WATER FROM LIMESTONE SPRINGS. THE HIGH BANKS ARE MADE UP OF SILT CLEANED OUT OF THE CANAL WHEN IT CARRIED THE MUDDY WATERS OF KING RIVER. WITHOUT POWER-DRIVEN MACHINERY FOR CLEANING THE CANAL THE IRRIGATION SYSTEM IS IN TIME PUT OUT OF COMMISSION BY SILT.

The most frequently recorded method of maintenance of this irrigation system, however, was the making of new canals obviously in part to avoid cleaning silt out of old canals. It would appear that time after time the system was largely ruined and fell into disuse, after which some leading man would take cognizance of the situation and secure the excavation of a new canal to take the place of the old in whole or in part. This occurred in 95 B.C. under Pai Kung; in A.D. 377 under Fu Chien; in 823 under Liu Jen-shih; in 958 under Hê Yu-chung; in 1006 under the Sung Emperor, Chên-tsung; in 1072 under Hou K'o; in 1108 under Chao Chuan; in 1314–1318 under Wang Chü; in 1645–87 under Hsiang Chung; in 1516–1532 under Hsiao Chung and Liu T'ien-ho; and finally in 1930–35 with the aid of the American China International Famine Relief Commission.[17]

The prime importance given to agriculture in this area is indicated by the fact that on several occasions in the Tang dynasty between A.D. 650 and 778, it is reported that mills using water from the canals built for irrigation were destroyed by Imperial order in order that the full volume of water might be used for the irrigation of crops in the plain. In A.D. 778, eighty mills were so destroyed, despite the fact that some of them belonged to a royal princess and the family of her husband.[18]

The later canals, beginning about A.D. 1072, required excavation in solid rock, which was formerly broken up by building fires upon surface rock, followed by pouring cold water over it.[19] Blasting with black powder was used in 1930–35. To raise the level of water in the river in ancient times to discharge into a canal which was then above the natural level of the river, barrages or diversion dams of different sorts were built.

References to efforts to raise the intake of the canal appear several times. The report of a commission made in A.D. 995 stated that formerly a barrage was built of stone in the river 100 paces broad, and an attempt was made to rebuild it in A.D. 991. This new effort was a barrage of wood, using over 11,300 stakes. After the irrigation for the year had been finished the dam was torn down and the wood kept for use the following year. Thirteen thousand men were re-

[17] See Ching-yang hsien chih (1841) 13/1a–4a and Appendix, 1/1a *ff.*, 3/2b–8a; Chinese Encyclopedia, 258/hui k'ao/6a *ff.*, 258/chi-shih/5b *f.*; S. Eliassen and Todd, The Wei Pei Irrigation Project in Shensi Province, *The China Journal*, 17: 170–180, 1932. O. J. Todd, *Civil Engineering*, 7: 553, 1937.

[18] Hsin T'ang Shu, 126/7a, 146/1b, quoted in the Chinese Encyclopedia 258/chi shih/3b, 4a *f.*; Life of Li Kan, *ibid.*; Yü-hai 22/11 a.

[19] Yuan Shih, 65/12 b.; *cf.* Chinese Encyclopedia, 258/chi shih/9 b.

quired for this operation, and were provided pro rata by those benefited, under supervision of the districts.[20] At one period shortly before A.D. 1314 bins of wicker-work filled with stones, 380 in number, were set up in the river yearly with a great amount of labor. Each bin was over 10 feet high. After the excavation of the Censor Wang Canal in 1314, 180 bins were used, in three ranks; those in the deeper parts of the river reached 15 feet in height. Every flood in the river threw them down in ruins. Holes cut into the rock held piles for the support of a Sung dynasty barrage (A.D. 960–1276). Wicker fences and barriers are reported to have been used in the Chien-teh period (963–967). These also had to be replaced yearly. An attempt to avoid this yearly expense through the building of a stone dam was given up.[21] In 996 the method used for building dams was to hold stones together by means of iron, melted and poured into the interstices.[22]

The reason for such diversion barriers became apparent in our field examination of the old canal system. We found where the original canal had taken water out of the King River. But now the river is about 60 feet below the level of the old canal. In the past 2,000 years the stream has been excavating its channel below the intake of this first canal. As the river lowered its channel barrages or barriers were placed across the stream to raise the level of river water. When this was impossible, it became necessary to dig a new canal extending the intake higher up the stream for head enough to flow into the canal. Establishing entirely new intakes of the main canal was done many times during the life of this project, as the record and field evidences show. One such new canal was extended upstream until it had to be cut through limestone rock of a gorge of the King River. But in time river erosion cut into this canal and made it useless. Still other canals were located and cut into the rock wall higher up the slope. We estimated that in places the highest canal

IN THE KING RIVER GORGE

INTAKE OF THE NEXT-TO-LATEST CANAL, ABANDONED BECAUSE THE HEAVY BURDEN OF SILT OF KING RIVER WATERS CHOKED UP THE CANAL SYSTEM. TODD SAMPLED THE WATER AND FOUND IT TO CONTAIN 46 PER CENT. SILT BY WEIGHT. THE SMALLER FLOW OF CLEAR WATER TAPPED BY CUTTING THE CANAL THROUGH A LIMESTONE FORMATION WAS USED FOR IRRIGATION UNTIL THE MODERN PROJECT WAS CONSTRUCTED.

[20] Ching-yang hsien chih (1841) 13/2 a.

[21] Sung Shih 94/19 a b; *cf.* Yü-hai 22/35 b, giving a report of the year 996 concerning such an attempt.

[22] Yü hai, 22/35 b.

VIEW OF TUNG-KWAN WITH THE YELLOW RIVER IN THE BACKGROUND

THE WEI RIVER JOINS THE YELLOW RIVER NEAR TUNG-KWAN. THE TWO GIANT TOWERS, FORTIFICATIONS OF THE GATE OF THE CITY, ARE BUILT OF BURNED-BRICK. HIGH, BURNED-BRICK WALLS ENCLOSE THE CITY.

had been cut fully 100 feet into the rock. A system of excavation and tunneling was used in digging these canals, showing capable engineering in ancient times. This last canal cut through an underground channel in limestone rock, bearing a stream of water. The clear water of this spring increased the flow of river water.

And now the modern or eleventh major relocation of the canal extends the intake still farther upstream. The dam or barrage is located at a point where the canal had to be tunneled 1,500 feet through the mountain. Modern engineering has only carried out the scheme of ancient Chinese engineers; it has had, moreover, the advantage of power-driven machinery and reinforced concrete construction to build more lasting structures. In fact, at the time of our inspection we heard of a proverb of long standing in the region, that the new canal must pierce the mountain to give water to the plain.

The latest dam is of concrete, with a core of masonry, 215 feet long, designed to pass a head of 50 feet of flood water. It is 30 feet high at the maximum and has a top width of 16 feet. It has a sluice opening (two originally) for flushing the mud through it at times of flood, when the silt content of the torrential waters is very high.[23]

Torrential streams intersecting the canals were carried over them on bridges of masonry to prevent blocking with detritus. This is reported for the canal finished A.D. 1110;[24] is again referred to in the Wan-li period of the Ming dynasty (1573–1619);[25] and is one of the rules set forth early in the Ch'ing dynasty.[26] The most recent canal has 11 such structures.[27]

For the latest canal of modern construction with a tunnel 1,500 feet long, an air compressor and pneumatic drill equipment were used besides hand drilling to prepare the rock for blasting, and concrete and masonry construction were used at head gates, dam and sluice-ways. Powered equipment gave modern engineers a big advantage over ancient Chinese engineers. Honor goes to these

[23] O. J. Todd, *Civil Engineering*, 7: 554, 1937.

[24] Chang-an chih (1787) Atlas hsia/76; also in Ming ed. Shang/50 a.

[25] Ching-yang hsien chih (1841) 13/4 a.

[26] *Ibid.*

[27] Eliassen and Todd, p. 178 and illus.; China International Famine Relief Commission Report for 1931, p. 63; O. J. Todd, *Civil Engineering*, 7: 553.

Chinese engineers of the past for their ability and achievements with simple masonry and hand labor.

Why were all these efforts required, and why despite them all was the irrigation system always losing its effectiveness?

One reason has already been suggested in the high silt content of the water. The ancient song celebrating the benefits from the two first canals, found in the "History of the Earlier Han Dynasty" (completed in A.D. 82) says: In one stone (*shih*) of King water there are several pecks (*tou*) of mud.[28] The significance of this statement becomes clearer when we learn that analysis of water at the intake of the most recent canal during freshets in 1931 and 1932 showed 46 per cent. of silt by weight.[29] Modern engineers consider a 5 per cent. load safe for the canals, and have allowed water with 20 per cent. of mud to pass through to the lands, but do not recommend the practice.[30]

Protection of the Wei-Pei Canal system from excessive silt had been attempted long before 1343 by the use of head gates to be closed at proper times, as indicated in the report of Sung Pingliang in that year. By the year 1737 the recurrent damage from silt had become so serious that it was decided to exclude entirely the water of the river from the canals, and an embankment was raised for this purpose, water from springs alone being depended on for irrigation, as field evidence indicates. The area irrigated was reduced to less than one tenth of the original project. This attempt was not entirely successful, for in 1754, in 1787 and again in 1816 the river

[28] See note 11. As dry measure the tou is 1/10 of a shih. Giles, Chinese-English Dictionary, 2d ed., 1912, No. 11427.

[29] Eliassen and Todd, p. 174.

[30] O. J. Todd, *Civil Engineering*, 7: 554.

VIEW OF THE MODERN DIVERSION DAM

BUILT STILL HIGHER UP THE KING RIVER GORGE THAN THE INTAKES OF ANCIENT CANALS. IT WAS POSSIBLE TO MAKE USE OF POWER MACHINERY AND REINFORCED CONCRETE TO BUILD A DURABLE STRUCTURE. BUT IT WAS NECESSARY IN THIS PROJECT TO DIVERT THE MAIN CANAL THROUGH A 1,500-FOOT TUNNEL TO GIVE IRRIGATION WATER THE HEAD NEEDED TO SUPPLY THE CANAL SYSTEM.

INTAKE GATE
OF THE 1,500-FOOT TUNNEL DIRECTING THE MUDDY KING RIVER WATER INTO THE MAIN CANAL.

OUTLET OF 1,500-FOOT TUNNEL
THE CHINESE NATIONAL FLAGS IN THE PICTURE REMAIN FROM THE OPENING DAY CEREMONIES.

broke through the barrier and silted up great lengths of canal.

On the main river and most of its branches storage is impractical because of the heavy silt loads in flood time, which would fill a reservoir in a couple of years.[31]

Another reason, apparently of even greater importance, for the repeated excavation of new canals, was the lowering of the river bed by erosion or scour, which was presumably more rapid because of the materials carried along by the water. In A.D. 1343 the censor in charge of Shensi circuits in his report to the Emperor said:

> It is found that the destruction of the value of canals in ancient and modern times is all because the river bed gradually becomes low, the mouth of the canal high, so that the water can not enter. So Pai could not but supplement the Cheng Canal, the Feng-li Canal could not but be opened after the Pai Kung Canal; and now the Feng-li canal mouth has in turn gradually become high. At present, measuring the distance of the mouth of Cheng's Canal above the surface of the water, it is found to be higher by more than 50 feet. The mouth of the Pai Kung Canal is at a height above the water level calculated as 13 feet. . . . At present the Feng-li Canal is also more than 7 feet above the water.[32]

Severe floods have many times destroyed barrages built to raise the level of water to the mouths of canals. Such was a yearly occurrence during part at least of the tenth and fourteenth centuries.[33] Floods also were responsible for silting and other injury to the canals during the period when it was attempted to exclude the river water, as already mentioned. Of recent years the maximum flood flow of the King River for rare periods has been estimated at 550,000 cubic feet per second. On the other hand, studies have shown a very

[31] Eliassen and Todd, p. 174.

[32] Quoted in Chang-an chih Atlas, hsia/17 b *f.*

[33] See above, p. 8 *f.*

low flow for short periods during January and June, with a minimum of less than 200 feet per second in January, and of 250 cubic feet per second in June, which is less than half the capacity of the present canal.[34] Some had hoped that over a million acres could be irrigated from this canal, but it has been found impossible to supply anything like that area on account of the small amount of water at critical periods and the high silt content when the water is high. An area of only 100,000 acres has recently been supplied with water, being one fourth of the area reported under irrigation in ancient times.[35]

The difference between the area now watered and that irrigated in earlier periods suggests deterioration of the regimen of the river since the early days of the Chinese Empire. While little is known historically that would furnish a basis for conclusions on this point, erosion conditions point in that direction. In the "Book of Odes," which reflects a period earlier than the earliest canals known in this region, *i.e.*, prior to 246 B.C., it is stated that the King River makes the Wei River muddy, with patches of clear water. The comment of Chu Hsi (twelfth century) states: "The waters of the King are muddy, and those of the Wei are clear, and the muddiness of the King appears more clearly after its junction with the Wei," and "The King River is muddy but not very muddy."[36] However, in recent times, the Wei has a heavy silt load, comparable to that now found in the King.[37]

Changes in the silt burden of the King and Wei Rivers as recorded in gazetteers of Chang-an, would agree with extension of farming out of the alluvial valley up slopes of the surrounding country. It is probable that agriculture first developed on an extensive scale in the alluvial val-

[34] O. J. Todd, *Civil Engineering*, 7: 554.

[35] *The Oriental Engineer*, Vol. 7, No. 3, p. 11; Eliassen and Todd, pp. 174–176; Todd, *Civil Engineering*, Vol. 7.

[36] Chinese Encyclopedia, "Mountains and Rivers," 258/hui k'ao/1 b; Legge, "The Chinese Classics," Vol. IV, Part 1, p. 56.

[37] O. J. Todd, *Civil Engineering*, 7: 556, 1937.

DIVISION OF THE MAIN CANAL INTO TWO LINES

TO SPREAD WATER AGAIN TO THE FERTILE PLAIN WHICH HAS BEEN UNDER IRRIGATION FOR MORE THAN 2,000 YEARS, BUT WITH INTERRUPTIONS DUE TO SILT CAUSED BY SPECTACULAR ACCELERATED SOIL EROSION OF THE LOESSIAL SOILS OF NORTHWEST CHINA.

AN AREA OF THE YELLOW RIVER DRAINAGE

WHERE GULLIES HAVE REACHED SPECTACULAR PROPORTIONS, ESTIMATED TO BE FULLY 500 FEET DEEP. NOTE THE REMNANTS OF TERRACING ON GULLY MARGINS SHOWING THAT LAND HAD BEEN CULTIVATED PRIOR TO HEADWARD CUTTING OF GREAT GULLIES. ALL LAND NOT TOO STEEP IS CULTIVATED.

leys. As population increased and pressure upon the land increased, the cultivation line was pushed up slopes higher and higher, as the senior writer has found reasons to believe in field studies in Shansi.[38] With clearing and cultiva-

[38] W. C. Lowdermilk, *China Jour. Sci. and Arts*, 14: 3, 1926.

A DROP ON THE NORTH BRANCH OF THE MAIN MODERN CANAL

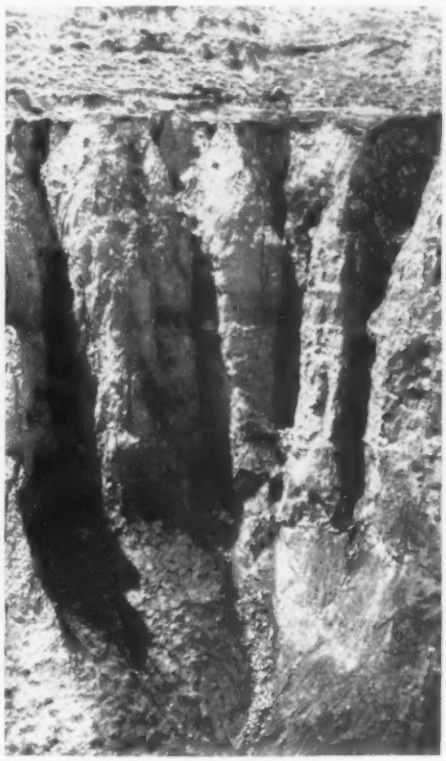
OF THE WEI-PEI PROJECT. NOTE THE KING RIVER WATER IS THICK WITH SILT. IT IS PROPOSED TO DIVERT RIVER WATER WITH NO MORE THAN 20 PER CENT. OF SILT. THIS AMOUNT, HOWEVER, SOON CREATES SERIOUS PROBLEMS IN SILT DISPOSAL. SILT RESULTING FROM SOIL EROSION OF LOESSIAL SOILS AND BANK-CUTTING OF CURRENT DEPOSITS OF SILT IN RECEDING FLOOD FLOWS PRESENTS A PROBLEM FOR MAINTAINING IRRIGATION MORE DIFFICULT THAN ANYWHERE KNOWN BY THE AUTHORS.

tion of slopes, soil erosion was accelerated to prodigious amounts as shown by enormous gullies of recent growth in these loessial lands of northwest China. The silt burden of flood waters increased to the fabulous quantities measured by the senior writer in Shansi of 24 per cent.,[38] and by O. J. Todd in Shensi of 46 and even to 50 per cent. by weight.[39]

The Wei Valley about Chang-an (Sian) was the center of population so that the extension of the cultivation line up slopes and farther away would follow upon gradual increase of population. It is probable that cultivation reached the head waters of the Wei River at a later time, which would account for the record that the Wei River was clear in former times and later became a muddy stream like the King River.

Possible causes for an increase in the silt content of the water and greater variations in flow are extensive deforestation, cultivation of slopes and overgrazing in the region drained by the river. Evidence of this conclusion is set forth by the senior author in an earlier paper.[40] The watershed of the King is in general included in the region of the loess highlands, of which Cressey says, "Much of the Highlands, except perhaps the desert margins, appears to have once been covered with a continuous forest."[41] Much of this has since been cut down, leaving traces in the higher and more inaccessible mountains and about temples and monasteries where it has been protected.

Sowerby, who traveled over much of this region, says: "In the mountainous regions of Shansi and Kansu, and over the loess hills of Shensi, where uncultivated areas occur, we find such small trees as the Hazel, the Birch, a small variety of Poplar and a stunted Oak growing in great profusion, and forming dense coverts for various kinds of game."[42] Considerable remnants of forest were reported by Licent in the upper part of the King River drainage



HEAD CUTTING OF A GREAT GULLY

A PART OF THE PACK TRAIN ON THE TRAIL WHICH IS BEING PUSHED UP TOWARD THE DIVIDE. THE HEAD OF THE GULLY SHOWN IN THIS PICTURE SCALES AT LEAST 210 FEET DEEP. SOIL EROSION IN THESE GREAT LOESS DEPOSITS REACHES FANTASTIC PROPORTIONS, BECAUSE OF THE UNIFORMLY FINE TALCUM-LIKE TEXTURE OF THE LOESS. GIVEN LARGE DIFFERENCES IN ELEVATION BETWEEN THE ORIGINAL LAND LEVEL AND STREAM VALLEYS, EROSION TAKES PLACE ON A VAST SCALE AND EXPLAINS THE PRODIGIOUS QUANTITIES OF SILT CARRIED BY STREAMS IN FLOOD FLOWS.

[39] Eliassen and Todd, p. 174; Todd and Eliassen, *Trans. Am. Soc. Civ. Eng.*, 105: 374.

[40] W. C. Lowdermilk, *Am. For. and For. Life*, July, 1925.

[41] Geo. B. Cressey, "China's Geographic Foundations," p. 199, 1934.

[42] A. de C. Sowerby, "Sport and Science on the Sino-Mongolian Frontier," p. 221, 1918.

LOESS-MANTLED HIGHLANDS OF THE YELLOW RIVER

SHOWING HOW THE LANDSCAPE IS CUT UP BY ENORMOUS GULLIES. WHEREVER POSSIBLE, THE LAND IS CULTIVATED TO WHEAT. THESE GULLIES ARE EATING HEADWARD, DESTROYING USEFULNESS OF THE LAND AND ADDING TO THE SILT PROBLEM IN TRIBUTARIES OF THE YELLOW RIVER.

area less than thirty years ago.[43] He also reports deforestation in part of this region.

It is also to be noted that agriculture has been practiced in this region from a remote antiquity. In the "Book of Odes" are references to cultivation of parts of the King drainage area by ancestors of the Chou dynasty,[44] which goes back to 1122 B.C. But such cultivation was at first confined to alluvial valleys.

Some parts of the watershed have been grasslands in historic times. These have been extensively colonized and subjected to grazing by close-cropping animals. The washing away of soil by the summer rains and floods and the deterioration of agricultural lands have been noted in local gazetteers.[45]

As has been pointed out in the case of Mesopotamia and other regions of Asia,[46] wars and internal disturbances are very liable to interfere with the maintenance of irrigation works and to cause their failure. These have probably played their part in the case of Wei valley irrigation system also. Some centuries of weakness and division of the country preceded the building of the new canal by Fu Chien in A.D. 377, during which period this region was repeatedly invaded. Internal disorders also preceded the making of the new canal in A.D. 823. The renewal of irrigation in A.D. 958 followed a period of political weakness and division under the Five Dynasties. The Mongol invasions in the early part of the thirteenth century may be held at least partly responsible for the ruin of the canals and embankments and the desolation of the land reported in A.D. 1240.[47]

Before the building of the latest or modern canal the region had been invaded many times, in 1546 apparently by Manchu Tartars; in 1631 twice by insurgent forces; and so again four years later. The disorders which attended the fall of the Ming Dynasty also affected this region in 1637, when San Yuan was plundered by the forces of Li Tzŭ-ch'eng.[48] Invasions by rebels and banditti continued at intervals, being reported in 1675, 1862, 1865 and 1867.[49]

From the vicissitudes of this remarkable irrigation system in the land of the Sons of Han, where the Han dynasty flourished in the Golden Age of China, it appears that a number of forces must be resolved to maintain such a system in a useful condition through centuries of time. Stream erosion in excavating its channel below intakes of canals was a difficult problem for the ancients to solve. To-day concrete construction makes it possible to establish more permanent base-levels of cutting. The silt burden of the river waters, especially in time of flood from heavy rains, interfered with the usefulness of the project and put it out of commission, and finally disorders brought on by internal troubles or from invasion brought about ruin of the system. Maintenance of an elaborate irrigation system depends also upon orderly government.

Internal disorders within a people may readily occur if they begin to suffer privations of food, as would occur when irrigation waters were lessened or stopped. It is a case of interdependence

[43] Emile Licent, Comptes rendus de dix Annees (1914–1923) de séjour et d'exploration dans le bassin du Fleuve Jaune, du Pai Ho et d'autres tributaires du Golfe du Pei Tcheu Li, 1924, Atlas, map. No. 76; p. 1321.

[44] Legge, "Chinese Classics," Vol. IV, Part II, pp. 437, 484–489; San-shui hsien chih, 1873, 10/4 a.

[45] Ku-yuan chou chih, supplement, 1909. 5/24b, 7/21, 8/42a, b, 9/19a; K'ung-tung shan chih, 1819, Shang/12b; Ch'ien chou chih, 1726, 4/1b; San-shui hsien chih, 1873, 10/8a *ff.*, 10/18 b.

[46] K. A. C. Creswell, *Man*, 15: 68–71, 1915.

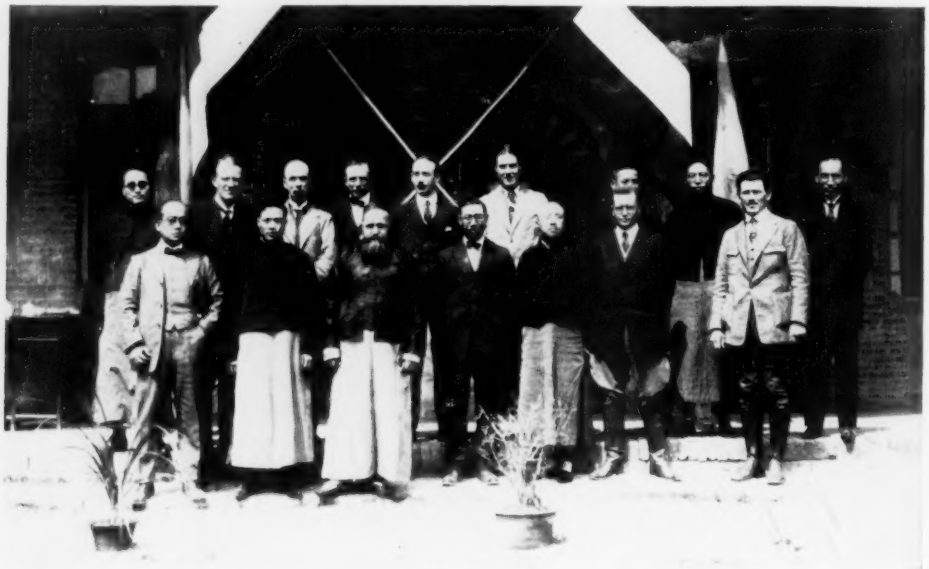
[47] Yuan shih 65/11b; Chang-an chih Atlas hsia/15 b.

[48] San-yuan hsien hsin chih (1880) 8/5 a.

[49] San-yuan hsien hsin chih (1880) 8/5b, 6a, 10a, 11a.

HEAD CUTTING OF GULLIES FROM TWO SIDES

CROWDING TRAILS TO THE TOP OF RIDGES. THE PACK TRAIN IS CROSSING A DIVISION HAVING ONLY SEVEN FEET OF THE ORIGINAL LAND SURFACE REMAINING. ON THE RIGHT THE GULLY WALL DROPPED 300 FEET AND ON THE LEFT, 150 FEET, MAKING THE CROSSING OF GAP A THRILLING ADVENTURE.



A GROUP OF CHINESE OFFICIALS AND FOREIGNERS

INTERESTED IN THE CHINESE INTERNATIONAL FAMINE RELIEF COMMISSION STUDYING REJUVENATION OF THE ANCIENT WEI-PEI IRRIGATION PROJECT. CHIEF ENGINEER, MR. LI HSIEH, STANDS ON THE EXTREME RIGHT; THE SENIOR AUTHOR, NEXT ON THE LEFT, AND O. J. TODD, FOURTH FROM THE LEFT IN THE BACK ROW.

between internal disorders and the breakdown of the irrigation works, where it is safe to set up as an objective of government the safeguarding of irrigation projects from damage and impairment by silt.

Summary

The succession of canals built to lead water from the King River for the irrigation of lands in Wei-Pei is an impressive instance of the efforts men have put forth to secure means of livelihood. The difficulties and partial failures encountered may be laid to physiographic changes as well as to failure over a large area to conserve soil and water, through suicidal farming and overgrazing of pasture lands, and the consequences of armed invasions either from outside or inside the country. Finally, after 2,000 years the constructive genius of the Chinese people has made use of modern engineering with power-driven equipment for excavation and construction to restore an age-old irrigation project to a semblance of its first condition. Lands that had lain bare and unproductive are made to yield crops again for its people. But still the high silt content of the irrigation waters remains a serious problem of maintenance. Silt control through erosion control on headwaters remains a necessary condition to the continuing success of this project, as its long history amply implies.

BIRTHS AND DEATHS IN THE UNITED STATES

While the United States set a new record low for infant and maternal death rates in 1940, the "Vital Statistics Summary: United States, 1940," finds that the general mortality rate increased slightly, from 10.6 per thousand to 10.8. This change was due largely to increases in deaths from heart disease, cancer and diabetes. The birth rate, however, also increased from 17.3 per thousand of population in 1939 to 17.9 in 1940, which is the highest recorded from the birth registration area since its completion in 1933. Possibly this indicates a cyclic change closing a long period of a declining birth rate.

This increase in birth rate has been accompanied by a reduction of the infant mortality rate to 47.0 per thousand live births in 1940, which was the lowest ever recorded for the birth registration area. However, the provisional infant death rate for 1941 is 46.2, which would seem to predict a further decline. In 1915 the infant death rate was approximately 100, so that the last twenty-five years has seen a decline of about one half. It is estimated that this amounts to the saving of the lives of 973,626 infants that would otherwise have been among the 3,264,365 infants that died during the past twenty-six years. This reduction in infant mortality has taken place in both the white and Negro races, although the rate for Negroes is still considerably higher than that for the white race. The rate of decline of infant mortality has been slightly greater for the Negroes than for the white race.

The lack of medical care in rural districts, of which so much has been said and written, did not raise the death rate on the farms to the level of the city population. The rural rate in 1940 was 9.8 per thousand of population, while in the cities of more than a hundred thousand residents it was 11.3. The highest rate (12.4) was in cities of between 2,500 and 10,000 population. Males have a decidedly higher death rate than females: 12.0 to 9.5 per thousand of population respectively. There is an even wider difference between the white and other races, the white being 10.4 and "other races" 13.8.

A comparison of the crude death rates for thirty-three specified countries, of which the latest information is for the year 1937, shows that of nations with a dominant white population Chile has the highest death rate. Yet Chile is the only nation on the western continent that has an extensive system of sickness insurance. The only nations that have a lower death rate than the United States are Denmark, Uruguay, Norway, New Zealand, Australia, Canada, Union of South Africa and the Netherlands. Denmark is the only one of these countries that has a nationwide system of compulsory sickness insurance.—*The Journal of the American Medical Association, July 18, 1942.*

SOARING OVER THE OPEN SEA

By ALFRED H. WOODCOCK

WOODS HOLE OCEANOGRAPHIC INSTITUTION

Convection Motions Indicated by the Gulls

From October until spring the air over the ocean off the east coast of the United States is, on the average, colder than the water. The heating of this air by the water produces ascending convective motions (motions hereafter referred to as thermals) which are columnar in form during light winds, and which change with higher winds to vertical sheets extending indefinitely up and down (parallel with the) wind. Unlike land thermals, these sea thermals maintain or even increase in strength under night-time or cloudy conditions. Also, as one moves southeastward (say from New York City) under average atmospheric conditions one finds thermals of increasing strength until one gets beyond the Gulf Stream—a condition due simply to the increasing difference between the sea temperature and the air temperature.

These convective motions of air over the sea are revealed by the soaring routines of herring gulls living in this air. The first suggestive feature of their movements lies in the fact that they are not seen far (100 miles or more) at sea until the fall, when cold air from the continent flows out over the warmer sea. The probable reason for this correlation is that the birds are unable to maintain a proper balance between their food supply and the energy requirements for flight until the development of the strong thermals of the fall and winter months make moving about over the sea physically easy.

Below a wind velocity of seven meters per second the birds circle about in columnar thermals, drifting along with the wind as they rise. If the rate of ascent in the thermal is great, the birds will have ample potential energy in the form of altitude to glide back to or beyond their starting point. At wind velocities of from seven to thirteen meters per second, birds soar straight to windward in a fast flight in which they

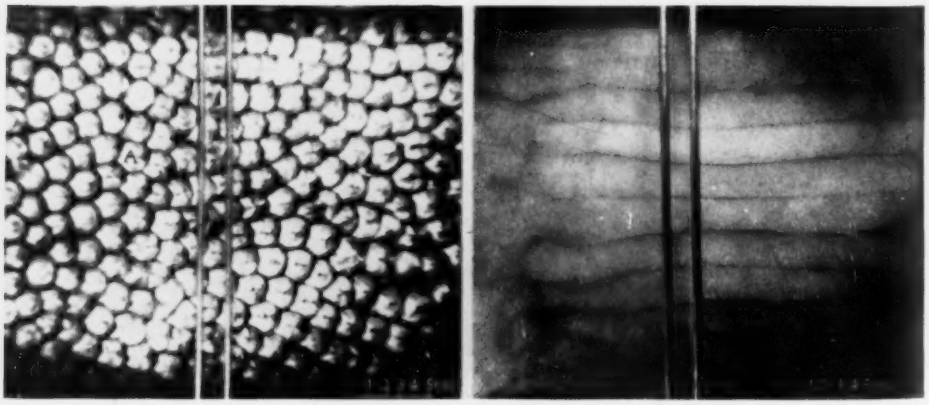


FIG. 1. POLYGONAL CELLS

Left: POLYGONAL CONVECTION CELLS INDICATED BY SMOKE—(SHEAR, 2.3 CM/SEC.) *Right:* LONGITUDINAL (STRIP) CONVECTION CELLS INDICATED BY SMOKE—(SHEAR, 10 CM/SEC.) THE DIRECTION OF FLOW IS FROM LEFT TO RIGHT IN BOTH PICTURES.

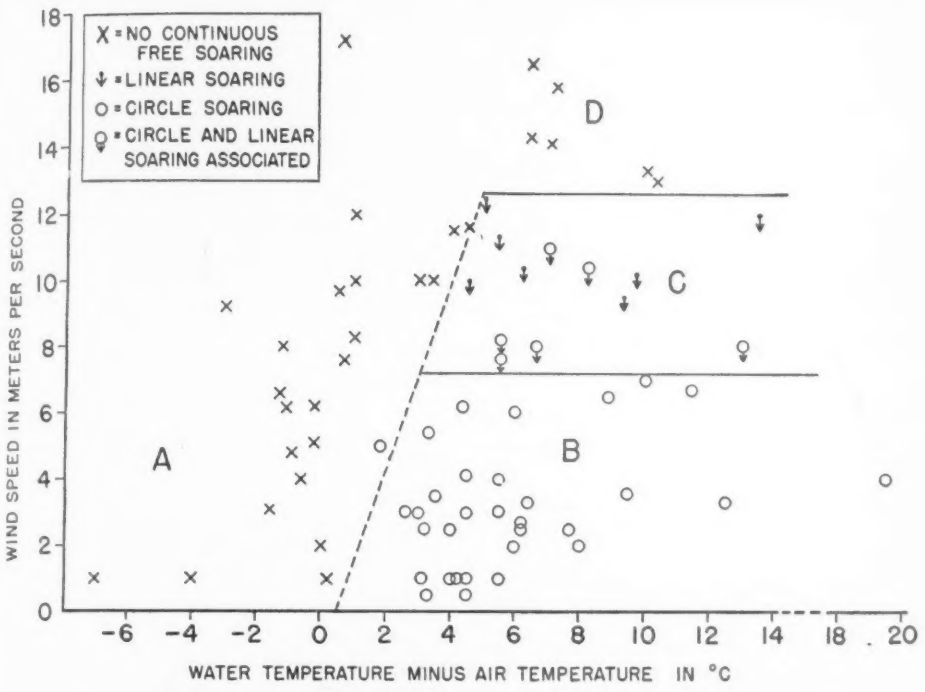


FIG. 2. FLIGHT RESPONSE OF HERRING GULLS
AT DIFFERENT WIND VELOCITIES AND AT VARIOUS RELATIVE AIR AND WATER TEMPERATURES.

gain altitude and over-the-water distance much more rapidly than in the circling flight of lower wind velocities. While moving against a wind of twenty-eight miles per hour, birds have been seen to disappear high to windward in a few minutes time.

Fig. 2 is a graph on which the flight response of the gulls is classified and plotted against the significant physical factors—*i.e.*, the wind velocity and the relative air and water temperatures. Each observation (*i.e.*, each symbol) represents an average period of about six hours during which at any time gulls might have been seen performing the flight routine which the symbol represents. It will be seen that circle soaring is confined to an area between 0.5 meters per second and 7 meters per second wind velocity and where the water is at least two degrees Centigrade warmer than the air. In air moving seven meters per second to thirteen meters per second, and which is more than four degrees Centigrade colder than the sea, the gulls can linear soar directly against the wind. The broken line and the upper solid line mark the approximate upper limits in wind velocity of patterned convective flow for the temperature differences of about plus two degrees Centigrade or more. Above this line (*i.e.*, higher winds) the vertical transfer of thermally unstable air probably takes place through turbulence.

Circle soaring is made possible by thermally unstable air rising from near the sea surface in columns. In light winds these columns are nearly vertical. As the wind increases they become tilted in the downwind direction. This is clearly shown when many birds enter a thermal successively. Not only is the tilt thus indicated, but also the extent of the vertical distribution of the gulls in

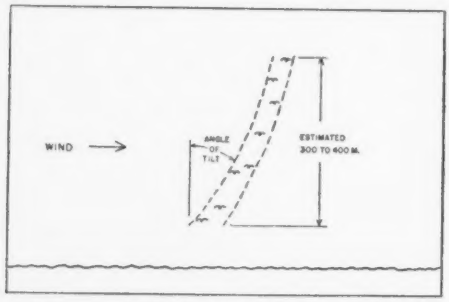


FIG. 3. DIAGRAMMATIC SKETCH SHOWING WHAT IS MEANT IN THE TEXT BY "TILT" AND "THERMAL CONTINUITY."

a thermal shows conclusively that these regions of ascending air have continuity, and are not merely bubbles of rising unstable air (see Fig. 3). Lange[1] (p. 120), speaking of thermals over land, says, ". . . thermals seldom are chimneys of air going up constantly; rather, they are bubbles repeating themselves at intervals." (Apparently sea thermals differ in this respect also.)

Linear soaring is made possible by thermally unstable air rising from near the sea surface in longitudinal strips, which are probably the rising portions of convection cells (diagrammatically idealized in Fig. 4). These strips develop at a wind velocity of between seven and thirteen meters per second, and when the sea is five degrees Centigrade or more warmer than the air. The soaring conditions when these physical relationships obtain give the birds a maximum freedom of movement. With ease they can maintain position or move to windward over the water at wind speeds of eighteen to twenty-eight miles-per-hour.

Both the columnar and strip thermals (as demarked by the gulls) start within 100 to 300 feet of the sea surface and extend up to an unknown height. Soaring altitudes of two thousand feet have been measured with a small range finder. Gulls are seen at much greater heights.

[1] Carl D. Lange, "Soaring Meteorology," Chapter VI of "Flight without Power," 248 pp. New York: Pitman Publishing Corp., 1940.

Elimination of Other Explanations for This Soaring

Anticipating objections that these birds may be using some other known or unknown means of soaring, it should be brought out here that there are three generally accepted (Horton-Smith) requisites for soaring flight. If a bird is soaring, one of three things is happening:

(1) The bird may be descending.

(2) The bird may be utilizing differences of horizontal velocity in the air.

(3) The air in which the bird soars may be rising. It is necessary here to prove that the third condition alone explains the soaring.

In all the circle and linear soaring observations used on Fig. 2 the soaring gulls ascended many hundreds of feet into the air and stayed up for long periods of time. This eliminates condition (1) from further consideration here.

Concerning the second condition, (*i.e.*, horizontal differences of velocity in the air) Rayleigh[2] (p. 465) has said that while using "dynamic soaring" in strata of different relative velocity a bird must, upon entering one stratum, turn around "until his direction is so reversed as to be with the wind of that stratum and contrary to the wind of the other stratum." But, in observations of circle soaring the birds turn both clock-wise and counter-clock-wise in the same area at the same time. Soaring on differences in horizontal velocity depends upon the increase of the wind with height (Idrac) and it is doubtful if this flight is possible far above the surface of the sea (Rayleigh,[2] p. 465). However, circle soaring depends only upon temperature differences between the air and water, and occurs many hundreds of meters above the sea surface. Thus it can be seen that there are several reasons why circle soaring can not be dynamic soaring:

[2] Lord Rayleigh, Rayleigh's Scientific Papers, Vol. 4, pp. 462–479. 1901.

(a) Circle soaring occurs only when the air is colder than the water; while birds can soar dynamically in air that is warmer than the water. (This difference alone is enough to clearly distinguish these two types of soaring.)

(b) Circle-soaring birds can turn in either direction in the same thermal at the same time; while dynamic soaring requires turning in only one direction in the same area at the same time.

(c) Circle soaring occurs at high altitudes; while it is doubtful if dynamic soaring is possible far above the surface of the sea.

In linear soaring the birds do not circle, but move in an apparently straight line. Since dynamic soaring requires a circling flight, then condition (2) (*i.e.*, differences of horizontal velocity) is also eliminated as a possible explanation for linear soaring. Therefore condition (3) only applies to the soaring flight considered in this paper.

Air Motions Used by the Gulls Compared to Experimental Convection Patterns

The sea offers a very steady source of heat, and, with a given wind, the shear between the air and the water is also fairly constant. Experimentally, such conditions are favorable for the development of convective patterns in fluids, with up and down flow occurring at regular intervals. The work of Chandra, Graham[3] and Mal shows the experimental development of various forms of strip and columnar (*i.e.*, polygonal) convection cells in shallow layers of unstable air. Fig. 1, *left*, shows polygonal cells, indicated by smoke in which the motion is down in the center of the cells and up at the cell peripheries. (Sometimes the motion is up in the center and down on the edges.) Fig. 1, *right*, shows the strip cells experimentally indicated by smoke.

[3] A. Graham, *Phil. Trans. Royal Soc. London*, 1934, 232: A, pp. 285–296.

These experimental workers have found that many variations occur both in the direction of flow within these circulations and in the form and size which they assume. These variations are shown to be due to changes in the temperature differences, to changes in the depth of the layer in which the circulation takes place and in the rate of flow within that layer. Brunt[4] (p. 287) suggests that sailplane pilots will eventually be able to tell meteorologists how the convective motions which occur in the air over land compare to those produced experimentally in the laboratory.

The air motions indicated by the gulls over the open ocean are similar to the experimental findings on the following points:

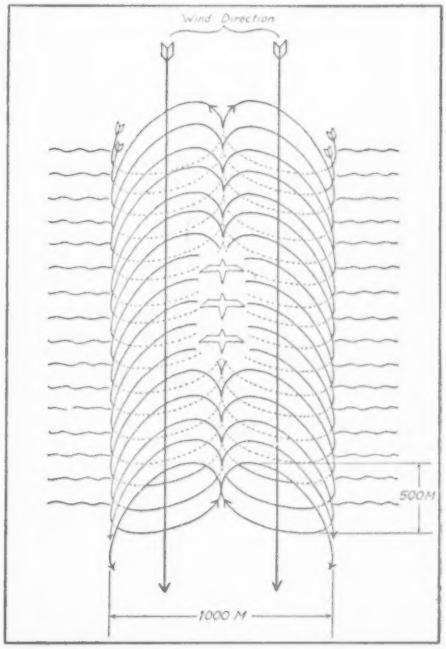


FIG. 4. LONGITUDINAL ROLL CONVECTION CELL

DIAGRAMMATICALLY IDEALIZED, SHOWING APPROXIMATELY THE PROPORTION OF DEPTH TO WIDTH. THE RELATIVE MAGNITUDE OF THE HELICAL MOTION IN THE DIRECTION OF THE WIND IS FORESHORTENED FOR CONVENIENCE IN PRESENTATION.

[4] David Brunt, *Quart. Jour. Roy, Met. Soc.*, Vol. LXIII, No. 271, July, 1937, p. 277–288 (Ref. to p. 287).

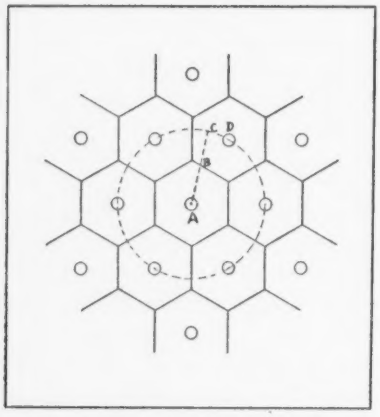


FIG. 5. STEADY STATE
HEXAGONAL CONVECTION CELLS (DIAGRAMMATIC).

(a) No patterned motion is indicated without thermal instability. (See Fig. 2, Section A.)

(b) Columnar circulations are set up in thermally unstable air at low wind velocities. (See Fig. 2, Section B.)

(c) Strip cells (*i.e.*, longitudinal rolls) are set up at moderate wind velocities and greater thermal instability. (See Fig. 2, Section C.)

(d) The convection pattern breaks down with high winds. (See Fig. 2, Section D.)

Discussion of Possible Use of Sea Thermals by Sailplanes

If the circulations which the gulls reveal in the air over the sea are also comparable to the experimental cells in their regularity and type of occurrence, then a sailplane pilot should be able to locate the up-moving air with a fair degree of accuracy, without clouds to guide him. This should be particularly true with the strip cells, for then he could regularly locate lift areas simply by moving cross-wind to the up-moving portion of the next parallel cell (See Fig. 1, *right*). With columnar cells a pilot in one thermal (See A, Fig. 5) might locate another thermal by noting the distance from A to the downdraft region (B), which he could presumably feel. Then, by running an approximately equal distance on the same course to C, and from there following to the right the periphery of a circle whose radius is AC, he should find the up-draft D. If columnar thermals at sea mark the centers of hexagonal convection cells, then any other course the sailplane pilot took from A, with similar subsequent maneuvers, would lead to one of the six up-drafts immediately surrounding the column from which he started. The distance between thermals should be about twice the height of the thermals (Brunt[4]).

The possibility that regular hexagonal convection cells develop in the air over the sea is, of course, questionable. The gulls show, however, that columnar and strip motion exists there, and the similarities listed above (a to f) encourage one to think that the experimental and gull-indicated motions may have other even more useful characteristics in common. Meteorologists such as Brunt[4] and Walker[5] have evidence that cells are sometimes set up over land. The inequalities of contour and heating over land would, however, tend to break up regular cell formations. The sea is much more regular in these respects, and might be expected to be more favorable for the development of convection cells of consistent pattern. The occasional behavior of gulls searching for thermals suggests that there are air motions between the columns which are used to locate the up-draft areas. Birds are seen to turn abruptly while in wing-flapping flight and move directly to a thermal, as if they had suddenly encountered an indicator of its existence while still several hundred yards distant. Pernaps peripheral down-draft areas enable these birds to orient themselves in relation to the up-drafts.

Walker[5] (p. 349) speaks of sailplane

[5] G. J. Walker, *Jour. Royal Aero. Soc.*, 37: 657 to 680, 1933; *Nature*, 134: 347–349. 1934.

pilots using "cloud streets," *i.e.*, thermals formed under strato-cumulus roll clouds or "longitudinal cells" which form parallel with the wind over the land. However, he says that these cloud streets are not so useful as the columnar thermals because in them a pilot is restricted to travel in one direction only. For the gulls, however, the longitudinal or strip cells over the sea afford a maximum freedom of movement; the birds being able to move in any direction relative to the water, even in winds of gale force. Brunt[6] (p. 75) speaks of a sailplane flight (Rotter 1936) of 203 miles, which was 138 miles off the straight down-wind line, as a remarkable example of the ability of a sailplane to "travel cross-wind." Gulls riding columnar sea thermals can easily follow the ship moving at right angles to the wind flow (relative to the water), soaring continuously.

Of course, this superior performance on sea thermals may be due to better soaring efficiency in the gulls, though Barringer[7] (p. 176) says, "The best modern sailplanes will outperform most soaring birds." Perhaps it is due to an ability on their part to locate thermals quickly. On the other hand, the difference may lie in the persistency and the regularity of the over-sea thermal as compared to the over-land thermal. Sailplane pilots might soon answer the questions raised.

The first two important questions about sea thermal soaring for the sailplane pilot are: One, will a pilot be able to return to a windward shore after a down-wind flight?; and, two, is the horizontal extent of the sea thermal sufficient for the use of a plane many times the size of a herring gull?

Perhaps a light power plane with a low minimum air speed would be useful to determine something of the size and strength of sea thermals. If not, then a sailplane pilot might start from a leeward shore (say Montauk Point, Long Island or Nantucket Island) in a cool northwest wind and try working to windward with sufficient initial altitude to assure return to port. In this way he could get an idea of the sizes of the thermals and of his ability to work to windward using them. These locations (*i.e.*, Montauk Point and Nantucket) are open to the possible objection that there may be too small an expanse of water to windward to build up an adequate supply of unstable air to form vigorous thermals. However, the gulls seem to have no difficulty at these distances off shore.

Significance of Seas as Source of Heat

If these sea thermals are of sufficient extent and strength for man soaring, they should be much more reliable than land thermals, due to the great source of heat which deep water supplies. The specific heat of water is over three thousand times that of air, so that when a cubic meter of water cools one degree Centigrade, enough heat is released to raise the temperature of over three thousand cubic meters of air one degree Centigrade.

Preliminary figures (Montgomery) on the average rate of heat transfer from the sea to the air by conduction are interesting. When a force three wind (Beaufort scale) is blowing over water which is 6.5 degrees Fahrenheit (average value from U. S. Department of Agriculture Climatic Charts of the Oceans, Chart No. 127) warmer than the air, 7.2 normal calories per square centimeter per day are lost by conduction to the air. Hence, across the water surface under a circular convection cell 1,000 meters in diameter enough heat would be transferred to raise the temperature of 12,420 cubic meters of air one degree Centigrade per second.

[6] David Brunt, *Nature*, 141: 3573, 712–716, April 23, 1938.

[7] L. B. Barringer, "Flight without Power." New York: Pitman Publishing Corp., 1940.

When a force five wind is blowing over water 6.5 degrees Fahrenheit warmer than the air, 12.8 normal calories per square centimeter per day are lost by conduction. This is enough heat to raise the temperature of 23,000 cubic meters of air one degree Centigrade per second for every water surface under a circular cell 1,000 meters in diameter.

These figures give a rough idea of the volumes of unstable air available for vertical circulations in the air over the sea along the east coast of the United States during the winter months under average conditions. Though the heating of the lower air one degree Centigrade will cause only small initial vertical speeds (the acceleration being 3.37 cm per sec. per sec. at 15° C), the great volume of unstable air produced would make possible a continuous thermal difference at considerable altitudes, thus permitting a building up of high vertical speeds (See Lange,[1] pp. 111 and 112). The addition of water vapor to the air being warmed at the sea surface increases the instability of the (already thermally unstable) air. A change in humidity from fifty to one hundred per cent. saturation at ten degrees Centigrade produces a change in the density of the air about equal to that caused by an increase in the temperature of the air of eight tenths of a degree Centigrade.

Concluding Remarks

Cold weather may make flights off the northern states impractical save in the late fall months. However, by moving southwestward along the coast towards Florida, one could find warmer air and at the same time warmer water. Sailplane flights have even been proposed over tropical seas, using a ship as a base for operations. This ship was located at that time in the Atlantic between Cape Verde, Africa, and Cape Sao Roque, South America. Whether these flights were made is not known, but the proposal is mentioned here simply to show that others have thought that sea thermals might prove useful for sailplane flights.

It is hoped that the increasing use of sailplanes by our air forces will soon bring about a testing of the potentialities of convective flow over the seas.

SCIENCE IN WAR AND PEACE

The scientific method in one sense is completely divorced from social consequences. Men of bad will, usurpers of human culture, marauders of our times can with unenviable cunning use the priceless time-tested, experimental method to fashion offensive weapons which can be used to annihilate the environment and the people from whom true science must bring the continuing progress of the world. The metallurgist, who makes possible a fine, keen butcher knife of stainless steel, a useful product of his technology, can do little to prevent the use of that knife for murder by a mad butcher.

In another sense, the utilization of the resources of our planet, including the knowledge and methods and mechanisms produced by science, is a real concern to those who are scientifically creative. It would be logical and not too much to expect that scientists take more than a democratically average interest in preventing destruction and aggression, misappropriation of our material resources, the distribution of good things of this earth among all the peoples, and the assurance of that essential minimum of food, clothing, shelter, education and freedom to all. This means that scientists and engineers must be more than creative specialists; they must be leaders in living and social organization, within the limits of their abilities.

Science can greet with equanimity the unreasoned criticisms that sometimes come to it, charging that science has created new and more deadly weapons. Of course it has. It has created mechanisms and devices for offense, as well as defense, just as it has brought into being all the homely, peaceful things of life, from a comfortable lounging chair to golf tees made of a new plastic.—*Watson Davis in an address before the Institute of Public Affairs, University of Virginia.*

PRESENT STATE OF THE THEORY OF STELLAR EVOLUTION[1]

By Dr. HENRY NORRIS RUSSELL

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HERSCHEL, almost a century ago, compared the student of the stars with a traveler visiting a forest. An alert observer might see there seeds falling to the ground, others sprouting, little saplings, sturdy young trees, monarchs of the forest, hollow, battered trunks and fallen boles mouldering into earth; and so, in one afternoon, attain all the data required to interpret the life-cycle of a tree.

The analogy is very tempting, but it fails at one vital point. We unconsciously assume that our traveler had a general knowledge of the processes of life. Otherwise he might conclude that oaks grew into acorns or that every blade of grass would in time become a tree.

Even with such knowledge, he would be at a loss unless he had visited a long-established forest, older than any tree in it. In a plantation of trees set out at the same time, or even in second- or third-growth woods that had grown undisturbed since fire or the axe had cleared the land, he would miss out important stages of life-history and might reach strange conclusions.

At the beginning of the present century, not enough was known about individual stars to justify any generalizations. Since then a great mass of information has been accumulated concerning distances, luminosities, surface-temperatures, diameters, masses and densities, providing abundant material for testing the predictions of theory. But the empirical methods of natural history proved inadequate to suggest a good theory.

[1] Based on an address presented at the Inter-American Congress on Astrophysics, Puebla, Mexico, February 19, 1942.

For example, we know that hot bodies tend to cool down; hence it was once supposed that white stars (hot on the surface) were in early stages of evolution, and gradually changed into red, cooler stars. The terms "early" and "late" applied to the corresponding spectral types persist almost to this day, as a sort of literary fossils bearing the mold of this extinct theory.

The problem of stellar evolution is not one of natural history, but of physics. Any reasonable theory must be a by-product of a physically sound theory of stellar constitution, which shows how the observable characteristics of a star-mass, radius, luminosity, etc.—are related to its composition and its internal structure. The central problem is this: Given a large quantity of matter of known mass and atomic composition, isolated in space; to find its configurations of equilibrium, and its steady states of slow secular change. The sequence of these changes defines the evolution of the stars.

The problem may be simplified by limiting the primary study to non-rotating bodies—leaving the complications resulting from rotation for later study (which is as yet scarcely begun). A second, and still greater, simplification arises from the fact that all observable stars are very hot, even at the surface. The properties of matter within them are thus greatly simplified, and general considerations of atomic physics suffice for their discussion.

The knowledge of atomic structure, especially that derived from ordinary and x-ray spectroscopy, is the foundation upon which theoretical astrophysics rests. We can now predict with assur-

ance the behavior of atoms even under the most extreme conditions of temperature and pressure which prevail within the stars. It is certain that the temperatures through most of the interior of a star are to be measured in millions of degrees, and that, despite the enormous pressures, the atoms are heavily ionized, or stripped of their outer electrons, reducing the lighter ones to bare nuclei. Two of the three relations which determine the constitution of the stars are now known with adequate accuracy—the *equation of state*, connecting temperature, pressure and density, and the *equation of energy transfer* between hotter and cooler regions. Both involve the state of ionization of the gas and the pressure of radiation, and both are complicated; but the calculations, especially for the opacity, have been greatly facilitated by the preparation of tables.

The third relation, the *equation of energy-liberation* from latent sources, depends normally on nuclear reactions, which are rapidly being investigated as nuclear physics advances. The transitions, so far known, are of the non-equilibrium type, in which previously existing stores of energy are liberated, by one-way processes. Reversible reactions, at equilibrium rates, are possible, but would be sensible only at temperatures very much higher than are to be anticipated in the stars. Under certain conditions, the release of gravitational energy by contraction of stars appears to be important.

The mechanical equilibrium of a star can be studied with the aid of the equation of state alone. For any "model" of given composition (in which the density is given, as a function of the central distance, subject to certain normalizing factors), the temperature required for equilibrium may be uniquely determined. If the equation of heat-transfer is added, the flux of heat through the mass can be found.

If these calculations indicate that more heat flows out through the outer surface of a thin spherical shell than flows into it through its inner surface, it must be assumed that the difference represents heat generated in some way within the shell. This is not disturbing; but calculations which show that less heat flows out of the shell than flows into it demand the existence within it of "sinks" of heat, in which it is transformed into latent energy of some other sort. According to our present knowledge, the long-continued existence of such a situation at stellar temperatures and pressures appears extremely improbable, and models which lead to it are discarded.

A great variety of possibilities remain. Two of these models deserve special mention:

(1) Eddington found, many years ago, that if the product of the rate of liberation of heat by the opacity is assumed to be constant, the mathematical analysis is very greatly simplified and leads to a definite model, with the central density 54 times the mean density. Results calculated from this simple model agree surprisingly well—though not perfectly—with such observational tests as can be made, and it is now widely called the "standard" model, though the physical assumptions upon which it is founded are known to be inexact.

(2) A physically much more acceptable model is the "point-convective." This has an outer region in which no heat is generated, and the heat-flow takes place by radiation through the hazy gas, and a small inner core in which all the heat is liberated, and the flow is so rapid that it has to be carried by ascending currents of hotter, and descending currents of cooler gas. The calculation of such a model demands laborious numerical integrations. Results have been obtained for the Sun (that is, for a body of the same size, mass and brightness)

and for Sirius. They lead to models fairly similar to Eddington's, but with higher central densities (64 times the mean density for Sirius, and 78 for the Sun).

When once we have an acceptable model, we may use it (as Eddington was the first to realize) to attack the apparently impossible problem of the chemical composition of the main interior mass of a star. We can find that of the star's atmosphere—the very outermost portion—of course, from the spectrum, but the interior is hidden under a hundred thousand miles of incandescent and effectively opaque material and might be supposed to be as inaccessible as anything in the universe.

However, if we are given the model on which a star is built, its mass, and its radius, the amount of heat which will leak out to its surface, and hence the star's brightness, can be calculated, provided that we know the atomic composition of the material. This influences the result mainly by changing the average "molecular weight" of the gas—taking this average for all the particles—free electrons and wholly or partly stripped atomic nuclei. When the stripping is complete, as it is approximately inside the stars, this gives a mean value of 0.5 for hydrogen, 1.3 for helium and nearly 2 for all other atoms.

The composition with which we have to deal depends therefore upon the relative abundances of hydrogen, helium and all the "heavy atoms" together. The larger the percentage of heavy atoms, the hotter the star will be inside, the more heat will escape to the surface, and the more brightly it will shine. When, however, the percentage of heavy atoms is very small, the gas becomes less opaque, heat escapes more easily, and a star of practically pure hydrogen or helium would be bright.

For the same composition, the luminosity increases rapidly with the mass, and decreases slowly with increasing radius. Change of model has usually a rather small influence. Strömgren, working with the easily calculated standard model, has thus shown that a body of the size and mass of the Sun, and containing hydrogen, heavy atoms, but no helium, would shine with the Sun's brightness if it contained 65 per cent. by weight of heavy atoms, and 35 per cent. of hydrogen, and also for 0.2 per cent. heavy atoms and 99.8 per cent. hydrogen—corresponding to the two situations described above. A series of solutions connecting these two exists, with hydrogen and heavy atoms ranging between the given limits and helium rising to 42 per cent. and returning to 0.

This, by itself, would leave us in great uncertainty. But we have said nothing yet about the process by which heat is liberated inside the stars.

Energy-liberation in main-sequence stars (including the Sun) has been fully accounted for by the already classical discovery of Bethe—the catalytic process by which carbon and nitrogen transform hydrogen into helium without being themselves consumed. Of the six reactions

$$C^{12} + H = N^{13} + \gamma \qquad N^{13} = C^{13} + \varepsilon^{+}$$
$$C^{13} + H = N^{14} + \gamma$$
$$N^{14} + H = O^{15} + \gamma \qquad O^{15} = N^{15} + \varepsilon^{+}$$
$$N^{15} + H = C^{12} + He^{4}$$

all have been observed in the laboratory, and it is now certain that under the conditions prevailing in main-sequence stars they would liberate energy at a rate of the right order of magnitude. The final particle reaction, which produces carbon, is of the order of a million times more probable than the radiative process producing O^{16}, so that the cycle is almost perfectly regenerative.

The point-convective model for the Sun gives a hydrogen content of 35 per cent. (if there is no helium) and a central temperature of 25.7×10^{6} degrees. The observed energy-production of the

Sun would be met by Bethe's cycle if the combined abundance of carbon and nitrogen was 0.0067 per cent. by weight. More plausible values are obtained by assuming the presence of helium, which, according to Strömgren, increases the hydrogen, diminishes the mean molecular weight and the internal temperature. As the rate of nuclear reactions varies as T^{17}, a larger quantity of carbon is then required.

The possible values for the Sun's composition (by weight) then come out:

Hydrogen	0.61	0.51	0.43	0.36	0.35
Helium	0.35	0.42	0.43	0.29	0.00
Heavy atoms	0.04	0.07	0.14	0.35	0.65
Carbon and Nitrogen	0.025	0.0063	0.0017	0.00026	0.000067
Ratio	0.62	0.09	0.012	0.0008	0.0001

The ratio of C + N to all heavy atoms is given in the last line.

It now appears that the Sun's interior can not contain much more than 61 per cent. of hydrogen, for in that case, even if all the heavy atoms were carbon and nitrogen, they would not suffice to run Bethe's cycle fast enough to keep the Sun shining as it does. If we had any independent way of estimating what proportion carbon and nitrogen formed of all the heavy atoms, we could find the composition of the Sun. The best information we have is an investigation by Unsöld upon the spectrum of the hot star Tau Scorpii, in which he finds that they form 16 per cent. by weight of all the heavy atoms. Taking this as a general guide, we may conclude that the second column of our table is probably much nearer to representing the Sun's composition than those on each side of it, while the last two columns are very improbable. It thus appears that the Sun now contains nearly as much helium as hydrogen. It is kept going by "burning" hydrogen into helium.

Hence we may be fairly sure that the Sun is not yet half way through its possible evolutionary course (as measured by this transformation). If it started with very little helium, it is now well on to half-way through; but if it started with a good deal of helium, it is in an earlier stage. Unless we can find out how much helium it had when it started shining, we can deduce no more by this argument.

We can work out, however, what the Sun was like in earlier stages of its history, and will be like later. As it turns its hydrogen into helium, the mean molecular weight of its material would increase and the internal temperature rise. This would cause a rapid increase in the supply of heat from Bethe's process, which varies roughly as the 17th power of the temperature. The rate of escape of heat from the interior to the surface, and into space from this, would also rise; but, to get the two to balance, the Sun would slowly have to expand, becoming a little larger, and much brighter and hotter. At last, when only a few per cent. of the hydrogen was left, it would cease to expand; but it would continue to grow brighter and hotter till the hydrogen was practically exhausted. Then it would draw on its gravitational energy, contract rapidly and end as a dense white dwarf star.

Table 1 shows these changes in diameter and luminosity, and the corresponding values of the spectrum and

TABLE 1

EVOLUTION OF THE SUN

Hydrogen Percentage	Molecular Weight	Radius	Luminosity	Spectrum	Abs. Mag.	Time Interval	Number of Stars
91	0.536	0.875	0.12	dK8	8.2	(3.9)	(0.04)
81	0.574	0.900	0.19	dK5	7.1	5.4	0.16
71	0.618	0.921	0.31	dK3	6.2	3.3	0.33
61	0.670	0.964	0.54	dG8	5.4	1.9	0.62
51	*0.731*	*1.000*	*1.00*	*dG2*	*4.7*	1.0	1.01
41	0.803	1.040	1.95	F4	3.9	0.52	1.55
31	0.894	1.076	4.08	A8	3.2	0.25	2.19
21	1.005	1.132	9.22	A3	2.6	0.11	2.74
11	1.149	1.184	23.5	B9	2.1	0.04	2.93
6	1.238	1.193	40.4	B7	1.8		
1	1.341	1.129	77.2	B5	1.5	(0.013)	(1.38)

absolute visual magnitude (which astronomers commonly use in describing the stars). The fifth line, representing the Sun as it now is, is printed in heavy type.

Upon comparing these calculated properties of pre-solar and post-solar stages with the known average values for stars of the various spectral classes, and belonging to the main sequence, it appears that the pre-solar stages would be hardly distinguishable in brightness from the general run of reddish dwarf stars. They would be considerably more massive than the average, but this could be detected only if, by good luck, they belonged to binary systems.

The calculated post-solar stages, however, are very much fainter, as well as less massive, than average stars of the same spectral types.

The distances and luminosities of some thousands of the brighter stars have now been measured, and not a single object of this sort revealed by reliable observations. Here we have a new fact, evidently bearing upon stellar evolution. What is its significance? It is usually said in explanation that the pre-solar stages are faint, and spend their energy slowly, while the post-solar are bright spendthrifts; so that the latter live their lives so quickly that, at a given instant, few of them can be found.

It is easy to calculate the relative times which our hypothetical Sun would spend in each of the intervals centering on a line of the table, and these are given in the next to the last column. The first entry, in brackets, represents the change from 91 to 86 per cent. hydrogen, the next 86 to 76, and so on, except for the last, which is for 6 to 1 per cent. Adding them up, it is found that the pre-solar stages of evolution should take longer than the post-solar, in the ratio of 15.1 to 1.3.

This looks favorable to the argument; but an important factor in the problem has been forgotten. Our conclusion so far is true for any particular star. But we astronomers make our lists of stars for observation by their apparent brightness. If we go down, as we practically always do, to a given limit of apparent magnitude, we get the stars of great real brightness up to a large distance, but record only those stars of small luminosity which are near us. This well-known observational selection gives a great advantage to the bright post-solar stages. When allowance is made for it, we get the numbers in the last column of the table—and now find the post-solar stages favored in the ratio of 11.4 to 1.3.

The number of stars in the solar stage itself (line 5 of the table) is 1.01. For every star brighter than (say) the 5th magnitude and in the solar stage, we should find more than ten in the post-solar stages. We actually find twenty in the solar stage, and none in the other.

Something is wrong. The calculations have been carefully checked, the physical theory is well founded. How about our assumptions? One—that the stars are strewn nearly uniformly in space up to the distance we have to consider—is known to be very nearly true. But we have tacitly made another—that the stars we are dealing with started their careers indiscriminately at all sorts of times. This is necessary in order that the numbers of stars in the various stages (unaffected by observational selection) shall be proportional to the durations of these stages.

We had no proof of this at the start; its consequences disagree violently with the observations. Hence it must be false.

Every thing makes sense if we assume that the life of the visible universe, since stars like the Sun began shining, has not been long enough for them to reach the bright post-solar stages. This conclusion has been reached by an argument, altogether independent of any measurement, or even estimate, of time-intervals in years.

Now the amount of energy liberated

by the transformation of 1 per cent. of the Sun's mass from hydrogen into helium is known, and would keep it shining at the present rate for just about one billion years. Hence the unit in which the time-intervals in Table 1 is measured is ten billion years. The longest estimate of the past history of the stellar universe—since things went on as they are doing now—is about six billion years (from Paneth's recent work on meteorites). Most methods indicate half as long or less.

The conclusion that stars like the Sun have had time for very little evolutionary change since the origin of the Galaxy is therefore not new—though the reasoning here presented affords an independent proof of it.

Stars less massive than the Sun are so much fainter that the time-scale of their evolution must be much slower. We see them now substantially as they have "always" been. The very luminous stars at the top of the main sequence present a very different problem. Each component of the eclipsing variable Y Cygni, for example, has 17 times the Sun's mass, and—as best we can estimate—30,000 times its luminosity. The transformation of its whole mass from hydrogen to helium would keep it shining at the present rate for only about 60 million years. Hence, such stars either have access to some still more gigantic source of energy (such as the hypothetical complete annihilation of atoms) or they started shining only recently on the galactic time-scale. The former suggestion finds no support—and many difficulties—in our present knowledge of nuclear physics. The latter, which till very recently was hard to understand, finds support in researches in progress by Whipple of Harvard and Spitzer of Yale. It is conclusively proved by absorption phenomena that scattered particles of dust and atoms and molecules of gas are widely distributed in interstellar space. Both these investigators have shown independently, and by somewhat different methods, that such particles may tend slowly to concentrate toward the equatorial plane of a rotating galaxy. Whether they can assemble in sufficiently great amounts to concentrate at last into massive stars is not yet fully investigated, but enough has already been done to make this line of approach appear hopeful.

TEMPERATURE CONTRASTS IN THE UNITED STATES

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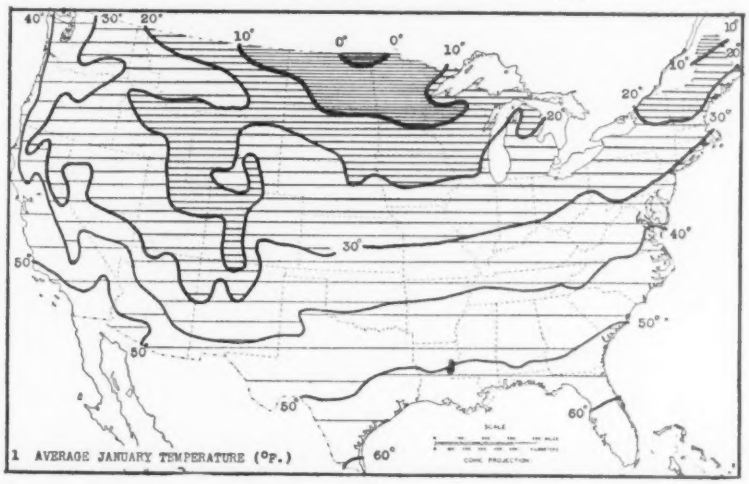
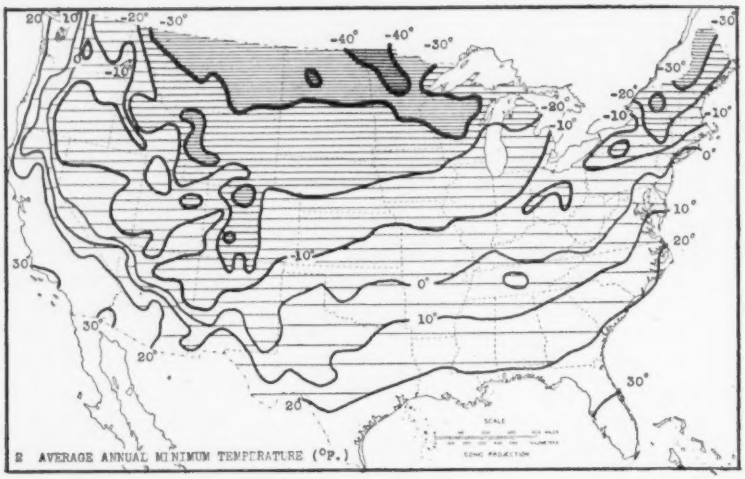
WIDE contrasts with respect to several significant temperature conditions in the United States are shown by the accompanying maps. They are based on the data for 40 years, 1899–1938, and most of them use records from about 5,000 stations. They therefore have a considerably firmer basis than had corresponding earlier maps, for example, those in the Atlas of American Agriculture (1928), most of which were based on data for 20 years for 200 to 600 stations. These maps are redrawn, shaded, and somewhat simplified, from maps in the 1941 Yearbook of Agriculture, "Climate and Man." The accompanying discussion is original.

Map 1 shows that the average January temperature ranges from about 60° F. in central Florida and southern Texas to below zero at the Canadian border near the center of the continent. The tempering influence of the winds off the Pacific Ocean is conspicuously shown—the northwestern corner of the country averages no colder in January than northern Texas or northern South Carolina. The Great Lakes also raise average winter temperatures appreciably. The Atlantic Ocean causes, however, only a slight rise in average temperatures near the coast, except in New England, because in January the average wind is from the west, not off the Atlantic. The depressing influence of the higher altitudes in the Rocky Mountains is evident, but the Appalachians cause only slight flexures of these isotherms.

Map 2, of the average annual minimum temperatures, shows a progressive northwestward decrease from central Florida, where a temperature slightly below freezing occurs at least once during each normal winter. Normally, the part of the country which is coldest in winter is an area west of Lake Superior, where −40° occurs at least once each winter. The tempering influence of winds off the Pacific Ocean is conspicuous on this map; at the western end of

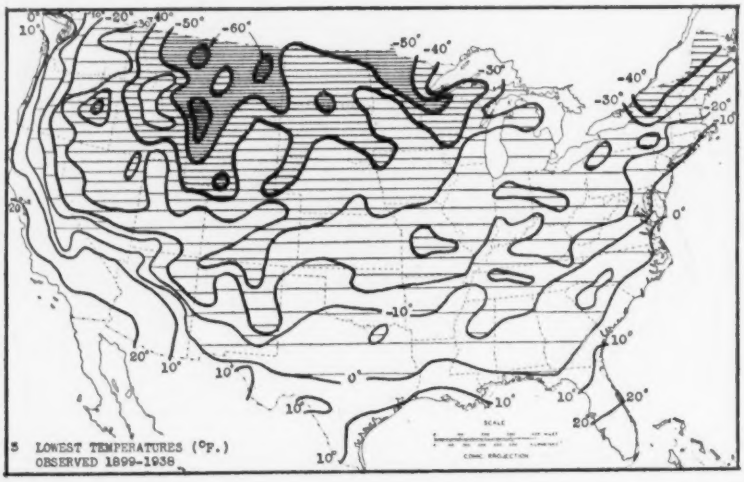


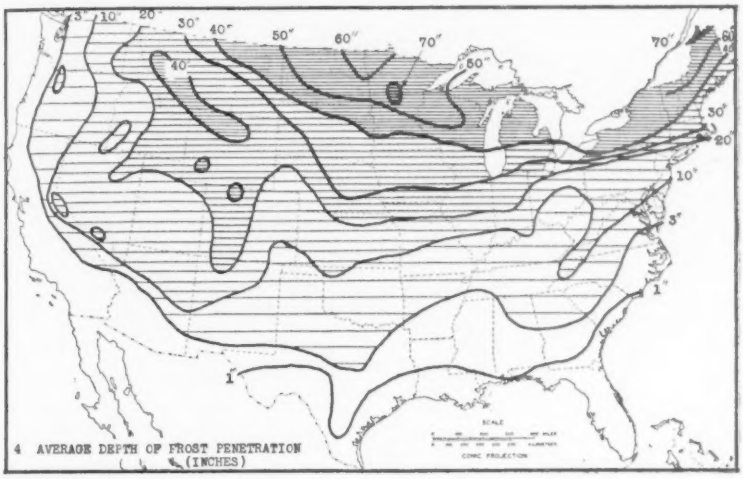
1 AVERAGE JANUARY TEMPERATURE (°F.)



the Canadian border the coldest temperature normally experienced is 60° higher than that recorded 1,200 miles to the east, and is no lower than that of northwestern Florida. The Great Lakes also interfere strongly with low temperatures; for example, the area just east of Lake Huron normally experiences in its coldest spell only −10°, while most of New England and Iowa experiences from −20° to −30°. The Atlantic has a greater influence upon minimum than on average January temperatures, apparently because of the large amount of fog and other condensation in exceptionally cold weather close to the coast. Low temperatures extend farthest south in the Rocky Mountain region, where the winters are dry and where the altitude is considerable. Note that −30° occurs each normal winter in Colorado, −20° in New Mexico and 0° in western Texas and northern Arkansas. The higher minima in the Pacific States reflects the greater amount of latent heat of condensation as well as the tempering influence of winds off the Pacific, for the winters are wet on the Coast.

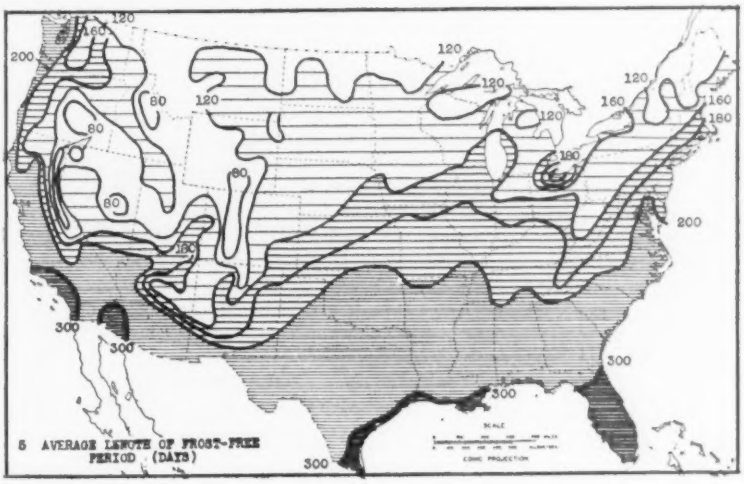
Map 3 shows that during the 40 years studied, 0° has been recorded at least once close to the Gulf of Mexico in northern Florida, and −60° in parts of

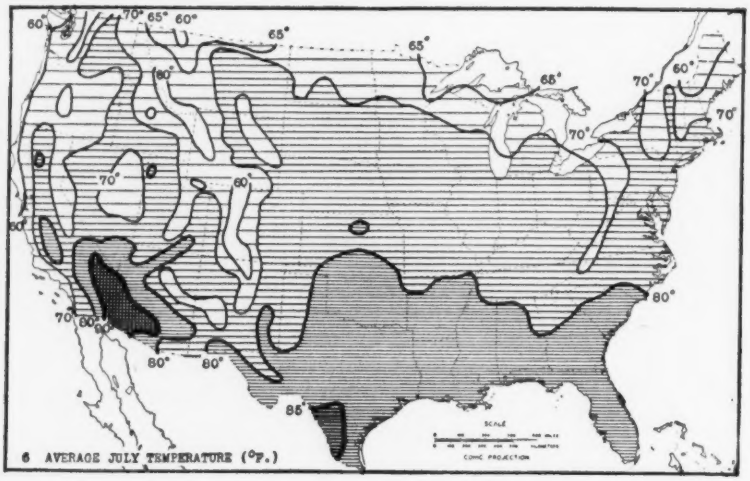




Montana and northwestern Wyoming. The much more extensive area of at least $-30°$ in the western than in the eastern half of the country reflects the influence of greater elevation there and of less atmospheric moisture. Although in the West temperatures of $-30°$ and colder have been experienced farther south than in the East, this map shows that $0°$ and $-10°$ extended about as far south in Florida and Mississippi as in Texas. This reflects the fact that exceptional cold waves are associated with great atmospheric highs which move southeastward from Montana. The tempering influence of the Atlantic coastal atmospheric conditions is shown conspicuously on this map. Several coastal stations at their coldest minute in 40 years were about 20° less cold than areas only 200 miles inland, despite a northwesterly wind blowing toward the Coast.

Map 4 shows that the average depth of frost penetration is more than 50 inches in a sizable area east of the Great Plains, but is less than 3 inches along the western and southern coasts. The deep penetration of frost in the Northeast, despite the normal presence of winter snow, shows that prolonged, severe cold penetrates a snow-cover. Indeed, a snow-cover is often conducive

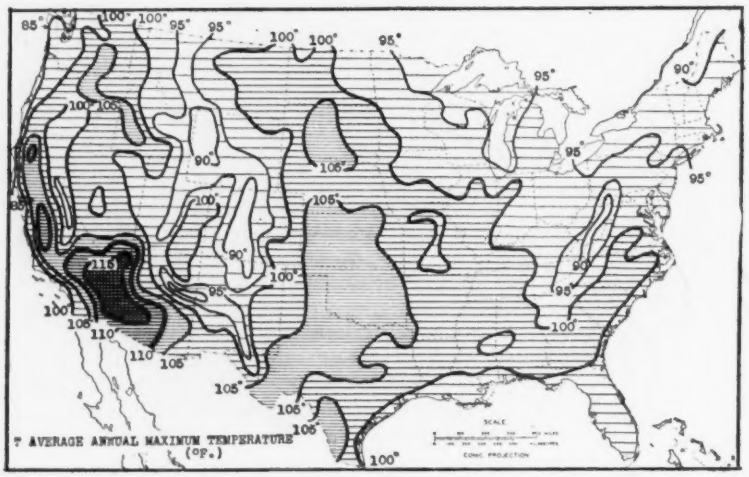




to exceptionally low atmospheric temperatures, by reducing solar heating and accelerating loss of heat at night.

The average length of the frost-free period (Map 5) varies from about 300 days at the south to less than 120 days along most of the northern border and in the mountains. The influence of winds off the Pacific and the Great Lakes is clearly shown on this map, and the effect of the Atlantic Ocean is more evident than in other maps of this series. The great influence of the thin air of high altitudes is shown by the presence of sizable western areas where the frost-free season is less than 80 days. Much of the northern Appalachians also is relatively cool, even being too cool for corn.

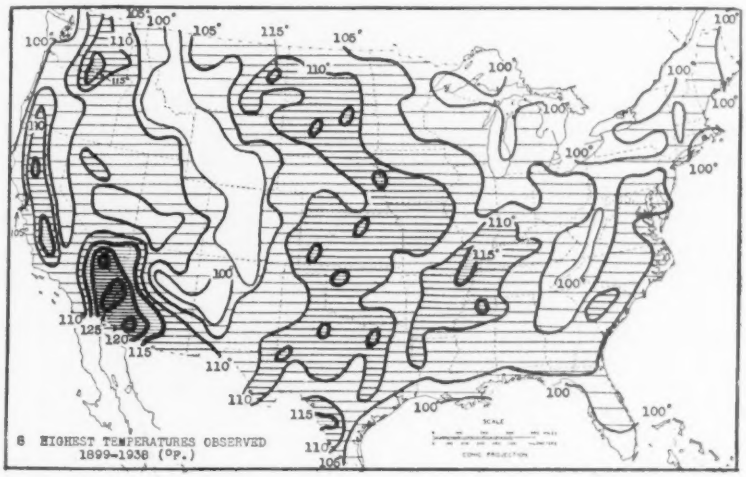
The average July temperature (Map 6) shows far less latitudinal contrast than is true for January, most of the country having a July average within a few degrees of 75°. Only small areas, except in the mountains and on the immediate Pacific Coast, have average July temperatures that are not above the optimum for mankind (about 65°, according to the evidence presented by Ellsworth Huntington and other inves-



tigators of the subject). The influence of the Appalachians is exceptionally evident on this map; western North Carolina has as low an average July temperature as much of northern Montana.

The highest temperatures experienced during the normal summer is the subject of Map 7. It shows that 100° or more occurs in most of the country each normal summer (generally late in July). The chief exceptions to this generalization are the Northeast, the west coast (especially north of San Francisco) and locally less than 100°. Southern Florida in the hottest weather is less hot than western Maine or North Dakota for three chief reasons: it has more cloudiness; the longest days are distinctly shorter; and sea breezes from the nearby ocean temper the heat. This map, the most irregular of the series, reflects local influences of sunshine as compared with cloudiness on record-making hot days. Other influences causing irregularity are water bodies, the dryness and color of the soil, and local differences in altitude.

A map, not published here, of average



the mountains and, strange to say, Florida. A temperature of 105° occurs each normal summer in sizable areas as far north as South Dakota and central Washington. Temperatures of 115° are normal on the hottest day of the summer in a part of the arid Southwest.

During the 40 years studied, the highest shade temperatures officially recorded have exceeded 100° in all but a few areas left unshaded on Map 8. The largest of these is in the western mountains. The latitudinal influence is different than might be expected. Near the Canadian border, several places have had maxima of over 115° (but less than 120°), while along the Gulf of Mexico the highest temperature recorded was

July wet-bulb temperatures shows a considerably greater latitudinal contrast than is shown by Maps 6, 7 or 8. The Gulf Coast, Florida and the coast of South Carolina have July wet-bulb temperatures averaging 75°, while much of the North and nearly all the West have averages below 65°; most of the Rocky Mountain plateau region has averages of less than 55°, as does the northern part of the Pacific Coast. Thus, although most of Florida seldom has a temperature as high as 100°, while South Dakota gets 105° each normal summer, Florida has a wet-bulb temperature averaging between 75° and 80° in July, while South Dakota's and Maine's averages are between 60° and 65°.

Hence, because of its humidity, Florida (except on the very seashore) feels much hotter than does South Dakota or Maine.

In brief, there are pronounced regional contrasts in temperature in the United States, which differences help to make the regional diversity which enables the United States to produce a great variety of crops, and to have within its own borders temperature conditions suitable for many other human activities, including recreation. Seven major influences producing the contrasts are: (1) latitude, through its influence on the angle at which the sun's rays penetrate the atmosphere and strike the surface, and hence in their effectiveness; (2) length of day and night; (3) altitude; (4) the ocean, with its almost uniform temperatures; (5) inland water bodies, especially the Great Lakes; (6) atmospheric humidity and soil moisture; (7) normal wind directions, including the course usually followed by atmospheric highs.

Latitudinal contrasts are evident in parts of all the maps, but are most conspicuous on the one of average January temperatures. Then, however, the influence of the angle of the sun is supplemented by the sharp northward decrease in the length of day. Latitudinal contrasts are least in July, when the longer days in the North largely counteract the influence of less effective insolation per hour. The influence of altitude is most evident during times of cooling, especially at night; the thinner air of higher altitudes enables a more rapid escape of heat. (During the day, however, thin air often permits a rapid surface heating.) The effects of altitude contrasts are therefore most clearly shown in the maps of minimum temperatures, especially of the duration of the frost-free season. The influence of the ocean is much more evident on the west coast than on the east because most of the United States has westerly winds (NW, W, SW) much of the time. The chief exception is the southern part of the country, which often has winds from the southeast or south in summer. Winds from the Pacific keep the adjacent coastal regions cool in summer and mild in winter. Winds from the Gulf and Atlantic help prevent nearby temperatures from rising to great heights in summer. The Great Lakes have a conspicuous influence upon minimum winter temperatures and upon the length of the growing season, because they remain unfrozen and yield much heat when the air is colder than they are. Their depressing influence on high temperatures is also evident. Low atmospheric humidity facilitates heating and cooling, while moist air greatly interferes in three chief ways: moist air is more often cloudy; the formation of dew, fog and frost sharply checks cooling, and their subsequent evaporation retards heating; moist air often yields rain, which means wet ground, usually relatively dense vegetation and occasional bodies of surface water. These latter retard heating and cooling. The influence of local contrasts in moisture conditions upon temperature are evident on all these maps, but are most conspicuous on those of the length of the growing season and of maximum and minimum temperatures. The significance of the direction of the prevailing winds is conspicuous with respect to the ocean, as already mentioned. The influence of the normal direction of movement of the atmospheric highs (from northwest to southeast into the South) is most evident on the map of exceptionally low temperatures.

THE FIRST ARTIFICIAL RUBBER TIRE

By Dr. ALBIN H. WARTH

CHEMICAL DIRECTOR, THE CROWN CORK AND SEAL COMPANY, BALTIMORE

THE following story is a true account of the public exhibition of the first artificial rubber tire ever seen in the United States. This artificial rubber tire represented the glorious achievement of a goal for which some of the greatest chemists in the world had striven for a century. It was in 1912 at the time of the Eighth International Congress of Applied Chemistry, which was held in New York City.

On Monday, September 9, 1912, there was rolled into the large lecture hall or amphitheater of the then new College of the City of New York a large rubber tire under cover, for it was held by the lecturer as a surprise package to be sprung on the audience of distinguished scientists from all parts of the world at the close of the lecture. The fundamental research in the chemistry of rubber and the making of artificial rubber belonged first to England, and then to France, Germany and Russia in succession, but the finishing touches to this research accompanied by laborious laboratory work of a team of fifteen chemists belonged to an industrial concern in Elberfeld, Germany, which was managed by a Carl Duisberg, the lecturer.

Duisberg lectured on the latest achievements and problems of the chemical industry as he saw them. He had with him the richest collection of diagrams, products and materials of all kinds that I had ever seen. They completely covered the long laboratory desk on the speaker's platform. Some of these things, particularly in the alloy steels, really heralded World War I, which was actually to follow two years later. But that is aside from the subject at hand. Duisberg, a short stocky man with a ruddy complexion, illustrated his paper by exhibits and lantern slides, to an audience that was delightfully enthusiastic to find so much that was new to them.

It is interesting to look back to the broad scope of chemical development on the Continent at that time, as it was outlined by the lecturer, who in well-spoken English said: "I invite you to make a flight with me in an airship, as it were, over the fields where the chemical industry holds sway and, from our point of vantage, to take a bird's-eye view of the latest achievements of the industry. Now and then, we shall make a landing and examine the most attractive features a little more closely." Then he proceeded with outlining one achievement after the other—the production of power; the production of by-products; the production of cold; the production of giant chemical equipment; quartz vessels; refined steel; nickel steel, chromium, tungsten and molybdenum steels, electro steel; electrolytic iron; sulfuric acid; ammonium sulfate; nitrogen compounds from the air; soda and chlorine; electrolytical detinning (patent process of Thomas Goldschmidt of Essen); peroxide of hydrogen; rare metals, artificial precious stones; coal tar preparations; synthetic colors, synthetic perfumes; artificial silk (viscose); acetyl cellulose; non-inflammable cellulose (cellox); and finally rubber—synthetic rubber.

We all felt a bit amazed at the outstanding progress that was being made and its important bearing on civilization. These commercialized developments should have spelt peace, but with

a few exceptions they signalled the coming of war. The airship had completed its survey of the fields and it was ready in the form of the Graf Zeppelin to challenge. Is it any wonder that Duisberg said in the spirit of Faust, "Who brings much will bring something to many." Duisberg closed his lecture with some words he quoted from Schiller in German, "Only the serious mind, undaunted by obstacles, can hear the hidden spring of Truth."

At the moment Duisberg lifted the artificial tire high in the air, bounced and rolled it, and the audience went wild with applause. So startling was this performance that many another scientist was politely incredulous. A few snickered and said, "I don't believe him—you can't tell me that tire is made of artificial rubber," or similar words to the same effect.

Professor Leon Lindet, of Paris, rose to his feet, and moved a vote of thanks, "Mais vous applaudirez aussi cette admirable cohort de chemistes—" The motion was seconded by an outstanding American chemist, the late Dr. Arthur D. Little of Boston. Little said: "Dr. Duisberg's masterly exposition of the splendid results achieved by the combination of German chemistry, German enterprise and German capital has been a delight and revelation to us all." Now carefully note these foresighted words of Little to which not enough heed was given, as we now only know too well. Said Little, mind you, thirty years ago: "We have in this country the capital, the enterprise, and I fully believe, the chemistry as well, required for equally great industrial achievements. That we can not thus far point to them is due to the fact that with us chemistry is too often left like Cinderella sitting beside the ashes of the laboratory furnace, while her two haughty sisters drive away together to the industrial ball. But some day, not far distant, her Prince will come and lead her forth to take her proper place before the world. . . . He will be wise in that chemistry which deals with men as well as learned in the chemistry which deals with things. He will be a Doctor of Chemical Organization, and we must not be surprised if his degree reads C.O.D." Little had the faculty of introducing a pun in his most serious remarks.

Now what was the expression of opinion on that beautiful large synthetic rubber tire that was unfolded for the first time and caused such consternation to William Henry Perkin, Professor of the university at Manchester, England, who happened to be one of those present at the Duisberg lecture. For hadn't Professor Perkin been the first to prepare "dipentene" in a synthetic way, a stepping stone to produce real rubber? Professor Perkin thought that Duisberg was taking too much credit for all these achievements, and plainly told him so. This resulted in a heated discussion that almost reached the stage of World War I. Perkin referred to his own father, the great Sir William Henry Perkin, as the founder of the chemistry which made such things possible, and reminded Duisberg that Germany to make artificial rubber on a large scale would need to depend upon England for a source of its raw materials.

The Duisberg tire was said to be the spare of a set of tires of artificial rubber that were prepared for the imperial automobile of Kaiser Wilhelm II. The rubber was prepared from "isoprene." The isoprene was derived from paracresol, which as a matter of fact was purchased from England. The process became known as the Elberfelder process, but today paracresol is not needed to produce isoprene. There are less expensive and more convenient ways of preparing isoprene.

An Englishman by the name of Wil-

liams discovered isoprene in breaking down natural rubber (caoutchouc) by heat distillation, and in 1860 observed that the isoprene, which is an oily liquid, thickened up with long contact with the air. In 1879 a Frenchman by the name of Bouchardat not only found that isoprene would, upon standing, slowly change into a rubber-like substance, but under certain definite conditions this change could be hastened by treatment of the isoprene with hydrogen chlorid gas. Tilden of London, in 1860, had tried the same thing but with somewhat discouraging results. Wallach, in 1887, found that light hastened a change of isoprene to the rubber-like mass. Harries, a German, in 1902 found that isoprene, when heated to 200 degrees Centigrade temperature, would yield dipentene (a double isoprene molecule), and other syrupy liquids. This was considered a stepping stone to producing real rubber. Dr. Fritz Hofmann, at Elberfeld, found in 1909 that by heating isoprene for eight days at a temperature of 120 to 200 degrees Centigrade, rubber could be formed. Later Hofmann found a still better rubber could be gotten by employing a lower temperature, namely, that of boiling water, and what is known as a catalyst, an activating chemical agent that hastens the reaction to a matter of days. To a Russian chemist, J. Ostramislensky, belongs most of the honor of working out the chemical structure of caoutchouc, and the related synthetic rubbers, three decades ago.

Artificial rubber tires were produced in the United States for the first time less than two years ago, according to recent news reports. The B. F. Goodrich Company, Akron, Ohio, is given the credit for producing the very first U. S. synthetic rubber tire, which was introduced in the market on June 5, 1940. The synthetic rubber used in these tires is produced differently from that used in the Elberfelder tire, and is said to have equal if not superior wear resistance to that of natural rubber. The synthetic rubber used by Goodrich is known as *ameripol*, which is attracting most attention at the present time for vast quantity production.

The world to-day turns its attention to producing synthetic rubber from the cheapest raw materials; petroleum in the United States, brown coal in Germany, and alcohol from potatoes in the Union of Socialist Soviet Republics. Extensive equipment is of course needed to carry out the chemical reactions, together with many fine chemicals of which there is needed an abundant supply. Some day we may all be riding around in our motor cars on artificial tires, made of synthetic rubber, and we will not need as many renewals as we did before, because the tires will have lasted much longer. At present the military needs must come first.

THE HISTORY AND BEHAVIOR OF A COLONY OF HARVESTER ANTS

By Dr. CHARLES D. MICHENER[1]

UNIVERSITY OF CALIFORNIA, BERKELEY

THIS paper primarily concerns observations on a single colony of the California red harvester ant, *Pogonomyrmex californicus* (Buckley), which is in the author's garden in Pasadena, California. The nest, like most others of the species, opens on nearly level ground through one or rarely more holes of considerable size (up to one-half inch or more in horizontal diameter and somewhat less in vertical diameter). Each of these is near one side of a broad, low mound, usually less than a foot in diameter, formed of earth and grains of sand brought up from the cavities below. As described by Wheeler[2] and Cole,[3] such mounds are much smaller than the great accumulations of sand and gravel gathered by the Texan harvester, *Pogonomyrmex barbatus* (Smith) and the western harvester, *P. occidentalis* (Cresson), yet considerably larger than the insignificant craters of *P. subdentatus* Mayr and *P. apache* Wheeler. During a brief part of one summer when the colony was exceptionally large, the particularly extensive accumulation of earth surrounding the hole was penetrated by galleries and chambers containing larvae and occupied by numerous ants, which ran out when the mound was disturbed so that the system of cavities partly collapsed. The structure thus showed an approach to that of the western harvester, which normally builds a large cone full of chambers.[2] At all other times, however, the mound was solid and excavations were below the surface of the ground.

Unlike the Texan and western harvesters, no large cleared area is maintained around the entrance of the nest by the California harvester ant, but there is a tendency to remove or restrict small plants growing close to it. Thus on June 27, 1940, and on subsequent days several ants were seen biting at various parts of a small plant of pimperel growing beside the hole. They were able to remove the tender tips, which were dropped to the ground and discarded, and thus prevented the plant from growing larger.

Prior to approximately 1924, no harvester ants were seen in the area where the nest under consideration now exists, although colonies a few blocks away were noted. However, in the summer of 1924 or the one immediately preceding it, four or five workers were seen at various times, although none were traced to the nest. The next summer more workers were found, as well as the small nest opening surrounded by a low mound of sand two or three inches across. During the next three or four years the colony grew rapidly, moving somewhat from season to season. During the years 1927 to 1931 it was as large as any colony of the species which I have observed, and it was during these years, probably as a result of the extensive subterranean tunnel system, that seasonal movements of the nest openings were greatest. The

[1] I am indebted to Dr. T. H. G. Aitken, Mr. B. Brookman, Dr. E. G. Linsley and my wife, Mary H. Michener, for reading of the typescript of this paper and for offering numerous valuable suggestions concerning it. Especially, I wish to express my appreciation to my mother, Mrs. H. Michener, for continued encouragement in this and other studies, as well as for numerous notes on the early spring and late fall activities of these ants.

[2] W. M. Wheeler, "Ants," xxv + 663 pp. (see especially pp. 284–293). Columbia University Press, 1913.

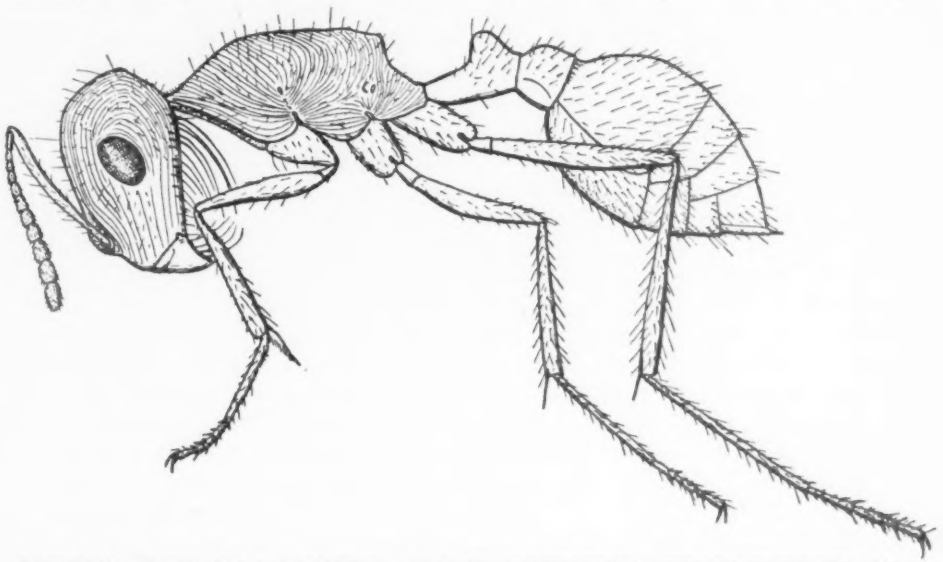
[3] A. C. Cole, *Ent. News*, 43: 113–115, 1932.

activities of a horned toad, *Phrynosoma coronatum blainvillii* (Gray), resulted in great depletion of the colony during the warm parts of the summers of 1932 and 1933. The lizard would lie beside the nest opening and eat the ants as they moved in and out. Its excreta seemed to consist almost entirely of ant parts, all of which came from this nest. By the fall of 1933, the colony was again small, but at this time the lizard disappeared. Since then the ants have increased moderately in number. Their failure to reach the abundance of the 1927 to 1931 period is, I believe, to be explained by recent environmental changes in the area involved. The California harvester is typically an ant of more or less open, sandy, dry, grass- and weed-covered areas. We have altered the environs of this colony by irrigation and by the planting of many shrubs and small trees, so that considerable areas previously available for seed collecting are now useless. The soil has never been as sandy as that in which this ant is normally most abundant. At the present time (July, 1940), the colony, approximately sixteen years old, seems to flourish even though not maximum in size, and I see no reason why it should not continue to do so, barring further human interference.

Seasonal History

The seasonal rhythm in this species is marked. From early November until February or March the nest is closed, although active individuals can be found by digging down a few inches at the site of the previous year's opening. In 1930 the nest was closed for the winter a few days before November 11, and was first opened on March 22; in 1934 it was opened about February 21, and in 1940 about March 22. Both in early spring and late fall the number of individuals outside of the nest on the surface of the ground is much smaller than during the warmer parts of the year.

In the spring the first opening to the surface has always been made within four or five inches of the previous summer's entrance. The early spring activities of 1940, the year in which they were observed most fully, will be described at some length. On each reasonably warm day during the period from February 22



LATERAL VIEW OF A WORKER OF THE CALIFORNIA RED HARVESTER ANT

until March 15, a very few, or sometimes as many as thirty or more harvesters could be seen wandering slowly and apparently aimlessly in the vicinity of last year's nest opening. Many of these were attacked or killed by Argentine ants, *Iridomyrmex humilis* Mayr. It is probable that activity on the part of all these harvesters was forced upon them either when a bird scratched deep enough in the soil to open the nest or when Argentine ants which were digging on the site of the previous year's harvester nest opening broke into the nest and allowed a few harvester ants to crawl up to the surface. Apparently none of the *Pogonomyrmex* which emerged from their nest during this period were able to return to it. However, on March 16, a warm day, a group of forty or fifty ants was seen around the mouth of each of two small tunnels in the vicinity of last year's nest opening. These ants stayed in compact groups, moved very sluggishly, and did no work. It is not certain whether they or the Argentine ants made the tunnels. Many of the harvesters were killed by Argentine ants, but some returned down the shafts, which were just large enough for them to pass through. From March 17 to 21 the weather was again cool and few ants were seen, but on March 22 and 23 some harvesters made two or three small openings barely large enough for them to crawl through with difficulty. Their activities were similar to those of the ants observed on the sixteenth except that some were seen scratching the soil with their fore legs, a process which will be described later; they showed no interest in seeds. Most of them returned into the holes, which were subsequently closed. From March 25 until April 10, another cool period, no harvesters were seen except those which chanced to emerge through Argentine ant holes. On April 11, another warm day, harvesters appeared at about ten tiny holes, some of their own making, some excavated by *Iridomyrmex*. They wandered about for a short time, then most of them returned to their colony; although they scratched with their fore legs, seeds did not interest them. By April 14 a larger opening had been made, a few objects were carried out of the nest, and although no ants went far from the nest opening or appeared to search for food, seeds placed near the opening were picked up and carried in. Cool weather subsequent to April 16 again stopped all apparently voluntary outside activity. Within a few weeks, however, a normal colony entrance appeared. It is thus seen that the commencement of activity in the spring is a gradual process, as is also the cessation of activity in the fall. Twice in early spring two major openings four or five inches apart were made at approximately the same time. Once one of these was closed in a few days, on the other occasion both remained in use for several weeks.

A new tunnel is usually made to the surface a month or two after the original openings appear in the spring. This second entrance is immediately enlarged, and in a day or two a typical mound surrounds it. In 1931 the new opening was made on May 15. On one occasion, when the colony was very large, ants were observed working after dark around the secondary opening for a day or so after its formation. This is in contrast to the usual closing of the hole before dark and is of interest in connection with Cole's[3] observations on nocturnal activity in the Mojave Desert. After a week or more during which both openings are in use, the primary one is permanently closed, the secondary opening being used exclusively. The distance between primary and secondary openings varies with the size of the colony. When it was large, as in 1929, the secondary opening was nine feet from the primary, while when it was small, as in 1934, it was only about

one and one-half feet distant. The total area in which openings have been made during the sixteen years of life of the colony is about 240 square feet.

Occasionally at almost any time of the summer a new opening may be made a few inches or even two feet from the one in regular use, and sometimes as many as four openings may exist at the same time within a few inches of one another, each with its own typical mound. Normally all but one of these will be gradually abandoned and in the course of a few weeks permanently closed. Except for the brief period in the spring already mentioned, I have but rarely seen two entrances more than a foot or two apart in use at the same time.

During the spring, usually until several days after the secondary opening has been made, most of the ants' activity outside of the nest is immediately around the openings. Bits of sand or earth are carried out and deposited on the mound, and many ants walk around and over the mound. Little or no food is collected, although seeds are accepted and carried into the nest if placed near the opening; few or no ants go more than a few feet from the nest entrance. After this time the ants wander more widely and bring seeds and other food to the nest in increasing quantities through the summer. During September and October activity gradually decreases, the working portion of the day becomes short, the number of ants seen outside is reduced until finally no ants appear at all, and the nest is closed for the winter.

Swarming: Although actual swarming has been observed but rarely, many winged females and a few males are observed each summer to come to the entrance of the nest or even to walk out into the sunlight for an inch or more, only to return. By far the largest swarm that I have seen was on July 12, 1929, a clear, warm day. About the usual number of workers was foraging away from the nest. At 9:30 A.M. queens and males were as abundant as the very numerous workers, running over the ground in an area about one foot in radius surrounding the nest opening. This region actually appeared red with ants. The males started to leave, at first slowly then more rapidly (up to about fifty per minute), flying upward from the area around the nest and disappearing against the sky. When they had nearly all gone, but before the rate of departure had decreased, females began to fly upward in a similar manner and in equally great numbers. Females in particular apparently need a high point from which to start their flight, climbing everything available. Nine were seen on one small stick standing about two inches upward from the surface of the ground. By 10:30 A.M. almost all the queens were gone, and by 11:00 A.M. no winged ants were in sight; most of the workers which had covered the ground around the nest had returned to it, so that activity was normal. For several weeks before and after swarming, queens were seen at the nest entrance; perhaps those seen afterwards left in an equally large swarm later in the year, but it seems more probable that one or several smaller groups departed during the course of the summer.

Two days after this great swarm, two dealated queens were found, each in a small shaft sunk about an inch into the ground. Neither survived to produce a new colony.

On July 15, 1939, from 10:05 A.M. (before which the nest was not observed that morning) until 10:35 queens left the nest at a rate of one or two per minute. Workers were very numerous on the ground near the nest. No males were seen, perhaps because observation was not started early enough. Many of the females instead of flying returned to the nest, and a few additional ones left the next day, which, like the preceding, was hot and clear.

Another swarm, similar to the last, was noted on June 27, 1940, a clear, warm day. It did not stop until about 11:00 A.M. Females departed at the rate of about six per minute. As usual, some alates were seen at the nest entrance on subsequent days. By the beginning of August no such alates were seen. Although Wheeler[2] reports a swarm before May 23 in the desert regions along the Colorado River, it is doubtful if alates are found so early in Pasadena.

Daily Activities

The daily activities of the ants are those most easily observed and most fully known. The nest opening is closed each night and reopened each morning throughout the warm part of the year. The evening closure in Pasadena takes place between sunset and dark in midsummer, before sunset in spring and fall, while the morning opening takes place sometime after sunrise.

The actions of the ants on a typical, hot, clear, July day will be described in some detail in order to exemplify the usual course of activity. The observations upon which this account is based were largely made on July 28, 1928, several days in July in 1929, and July 14 to 16, 1939, and have been verified and augmented by numerous incidental or brief visits to the nest.

The ants begin to open their entrance hole about 6:45 A.M., shortly after direct sunlight strikes their mound. Ants within dig and push their way out through the plug at the mouth of the hole. Sometimes as a result of digging from within, a part of the plug will cave in on some of the ants, and a number of dust-covered individuals will crawl out, followed by clean ones which must have been farther from the scene of the collapse. By alternate scratching movements of the fore legs, assisted by the mandibles for larger objects, the ants which have come out gradually increase the size of the opening by distributing the material of which the plug is made over the surrounding mound. At this time on a warm day, the temperature, taken by laying an uncovered thermometer on the ground beside the nest, has reached about 82° F. On a cool, foggy morning the hole may not be opened until 7:30 or 8:00 A.M., and then at a temperature of 70° F. the ants are very sluggish in their movements. On one occasion when the colony had two openings about two feet apart, one was shaded by bushes in the morning for about an hour longer than the other. The shaded one was not usually opened until nearly half an hour later than the other on sunny mornings, although on foggy mornings the two were opened at the same time. From the time the nest is opened until about 8:00 A.M. on a sunny day, many ants work around the nest carrying various small sand grains, bits of earth and other objects out of the hole and dropping them near the margin of the mound. At about 8:30 A.M. ants begin to walk away from the nest in search of seeds and other food. They leave in all directions, never in a trail; yet their wanderings are not entirely aimless. As observed on many occasions, the majority collected seeds from bird traps some fifty feet from the nest. In order to get there they followed the garden path around two sides of a square rather than taking the direct route across rough ground and among plants. During the summers of 1939 and 1940 no seeds were kept at this location, and the ants radiated much more evenly over the surroundings, picking up weed seeds and the like. Individual ants followed from the nest to the source of food and back did not follow exactly the same route on the return that they had taken on the way out; often the two would be as much as six or eight inches apart. (Further notes on the movements of the ants and results of experiments concerning their

mechanism of orientation will be given in a subsequent section.) Ants were never seen over one hundred feet from the nest and rarely that far. Many apparently carry nothing on their return journey; perhaps they have minute objects in the mandibles or infrabuccal chambers. By 9:30 A.M. they become less active, fewer going out of the nest; by 10:00 A.M., with a temperature of 121° F. on the ground, few leave the nest, although a considerable number are still returning from their morning's foraging trips. By 10:30 A.M. none are returning from or leaving on long journeys, although a few run rapidly around the vicinity of the nest opening, getting as far as a couple of feet from it. The temperature at the surface of the ground at this time is about 129° F. All the ants in sight during the hot part of the day run at a much more rapid rate than when the ground is cooler. By 11:00 A.M. only one or two ants are in sight at a time and these never get more than a foot from the nest opening, to which they quickly return. Never is any attempt made to close the nest at midday, in contrast to Cole's[3] Mojave Desert observations on this species. From 11:30 A.M. until 12:30 P.M. ants come out only an inch or two from the opening and remain in the sun only a few seconds at a time. The temperature at the ground surface is then about 133° F.

If at such a time an ant is taken some distance away from the nest, it will rush about at a tremendous speed, climbing each pebble or stick it reaches and hesitating in such places above the hot, level surface before descending and running until another elevation is found. If kept down on the ground level, the ant will die in less than one-half minute.

Gradually as the temperature lowers in the afternoon, more ants become evident, wandering farther from the nest opening, so that by 1:40 P.M., with the temperature about 125° F., seven or eight ants are often visible at one time. By 2:30 P.M., when the temperature has fallen to 115° F., many ants are leaving and entering the nest and going long distances for food as in the morning. This continues until about 4:30 P.M., when the number on long excursions decreases considerably. By this time the temperature is about 90° F. and the ants move much less rapidly than when it is hotter. About 3:30 P.M. considerable numbers of ants begin to congregate around the mound at the nest entrance, going in and out of the hole and carrying various objects around more or less erratically, often seemingly without much reason.

At 4:40 P.M. closing of the nest opening for the evening has already begun, and by 4:50 P.M. a good many ants are working on this. The technique used is to scratch very rapidly (or less rapidly as the temperature drops) with the front pair of legs in the fine dust around the hole while walking slowly forward on the middle and hind pairs of legs. When a grain of sand one-fourth to one millimeter in diameter is uncovered in this process, it is grasped in the mandibles, carried to the opening of the hole and there dropped. At 5:40 P.M. the opening is about half closed, and only thirteen or fourteen ants are left working outside. Progress is slow, the number of ants outside decreasing to five or six at 6:15 P.M., when the opening is about three-fourths closed. At 6:30 P.M. the work is complete and only three or four ants are outside. The number of ants visible at various times during the closing process varies slightly from season to season. The numbers just given were those of July 28, 1928. During July, 1939, more ants took part in the closing activities, and on July 14, 1939, twelve ants were left outside when the hole was closed, the largest number I have ever seen. The ants which finish closing the nest and remain outside continue occasional er-

ratic scratching until long after dark. From dark until about 9:30 P.M. about half of those outside wander aimlessly and slowly, one by one, to weeds growing a foot or more away and often climb up as much as an inch into them, there spending the night. The other half of the group remains at the entrance of the hole until morning. As the temperature goes down, activity almost entirely stops, a condition reached slightly above 65° F. In the morning when the nest is opened, those ants which spend the night at the entrance and at least some of those which wander into the weeds remingle with other members of the colony. I have often seen the nest at night when no ants were in sight and am inclined to believe that during most of the year, especially the cooler parts, those ants which stay outside, if any, are very few in number and all go into the weeds or other protection for the night or are killed by the Argentine ants.

On cool or overcast days during the summer, the nest may not be opened until 8:00 A.M. or even later, and activity continues unabated through the middle of the day.

The shortening of the daily periods of outside activity in spring and fall is much greater than would be expected. Thus on April 12, 1940, with the temperature on the surface of the ground as high as 125° F., the ants were active for only a couple of hours at midday, closing their small holes at a time when the thermometer read 95° F. From such a state of feeble activity they gradually change to the point in midsummer where the nest is open, although the ants are sluggish, at temperatures as low as 65° or 70° F. As fall approaches, the period of activity is again shortened more rapidly than the decrease in length of the days. Thus on September 7, 1939, a clear, warm day, the nest was opened at 8:45 A.M. and closed at 2:30 P.M., the early closure perhaps resulting from late afternoon shading by bushes. The next day it was closed at 3:00 P.M., even though the temperature of the ground surface was then 91° F. On September 9, the hole was opened at 9:00 A.M., when the temperature was 83° F. A brief period of lower temperature resulting from clouds caused the nest to be closed, but it was reopened at 10:00 A.M. when the ground temperature was 98° F. Other observations made in the fall indicate that the shortening of the daily period of activity is general, and that it continues gradually to a point where the nest is not opened at all.

As will be seen from the preceding descriptions, the activities of the ants at any time of the year are well correlated with the temperature of the ground surface. The seasonal differences in the temperature at which certain activities take place are perhaps related to the temperature below the surface, which varies with the total amount of heat absorbed and radiated and would be expected to be higher in midsummer when the days are long than in spring and fall, even though the surface temperatures during these seasons might be the same for certain periods of the day.

In connection with these observations, Cole's[3] notes on the habits of the species in the Mojave Desert are interesting. The hot climate there seems to affect the events of the day considerably, for he says: "Harvesting activity seems to be confined to the early morning and late evening hours. Many of the ants even work at night. During the heat of the day I found the entrances of all nests of *californicus* closed with sand or pebbles. When nests were opened under these conditions, the ants were from one to a few feet below the surface where the soil temperature was noticeably lower." Since Cole gives neither time of year nor ground temperatures, it is impossible to correlate these observations well with those made in the cooler climate of Pasadena.

The high temperatures at which *Pogonomyrmex* works to best advantage are doubtless correlated with the fact that this is a genus of primarily desert insects, which probably originated in a dry area and now occurs in regions characterized by aridity and hot summers in both North and South America. Pasadena is probably considerably cooler in summer, and perhaps moister, than most areas in which these harvesters occur.

As already stated, the movements of the California harvester are most rapid when the ants are very hot. When cool, as in morning or evening or on many spring and fall days, harvesters are comparatively sluggish. At such times, as pointed out by Shapley[4] and Tulloch,[5] the small introduced Argentine ants, which are active day and night, torment the harvesters greatly as they work around the nest. The ants which close the opening in the evening are particularly hampered by *Iridomyrmex*. Should a harvester come upon an invading Argentine ant, the former will often grasp the smaller ant in its mandibles, and curling the abdomen under the thorax, sting the intruder to death and drop it. When the temperature is low, however, the harvesters are commonly too clumsy to do this successfully. The usual thing is for the Argentine ants to cling by means of their mandibles to the legs and antennae of the *Pogonomyrmex*. This greatly disturbs, the latter, especially if several of the smaller ants attack a single harvester in this way. Individuals of *Pogonomyrmex* may eventually be killed by the Argentine ants. When the temperature at the surface of the ground rises above 85° or 90° F. the Argentine ants cease activity so that the harvesters are not bothered by them during the time of day that the latter are most active.

The primary food of the California red harvester is seeds of almost any kind small enough for a single individual to carry. Rarely if ever do two or more cooperate in carrying food of any kind to the nest, no doubt primarily because foraging trips are essentially solitary activities. Bird droppings are often carried into the nest, as are also dead and injured insects. Food dropped at the entrance of the nest is readily accepted. Often if a pile of seeds is placed there, some are carried away from the hole instead of into it; bits of meat or injured insects are immediately attacked with great vigor by many ants, whose first act, apparently, is to suck some of the liquids from such food. Later, or even as this process goes on, the pieces of food are broken up and carried into the nest. Seeds are apparently recognized as food only when touched or nearly touched by the antennae. Ants whose antennae were cemented to the head by fine flour paste or by water putty wandered over seeds without giving any evidence of recognition, but if one antenna were freed and if it touched a seed, the ant would immediately pick it up.

Individual Behavior and Orientation

As has already been stated, these ants do not follow any recognizable trails as does the Texan harvester, but each individual follows a somewhat different route away from the nest. An ant leaving the nest usually travels more or less directly for a certain distance, often many feet, after which it wanders apparently at random over a considerable area until it finds a seed or other object to be taken back to the colony. It then grasps this object in its mandibles and returns more or less directly to the nest on a route which is almost always at least a few inches from that of the outward journey. Should there be two or more entrances to the nest, the ant normally returns to the one from which it

[4] H. Shapley, *Psyche*, 27: 72–74, 1920.
[5] G. S. Tulloch, *Psyche*, 37: 61–70, 1930.

emerged, although if on its return journey it happens to cross the mound surrounding another, it will usually enter that opening. When one of two or more open holes is permanently closed, it often happens that for two or three days thereafter a few ants will be seen scratching around the entrance of the recently closed hole as they would if it were to be opened from below as usual in the morning. By marking with fine powder numerous ants returning to the nest from one side, it was found that their next trip from the nest, which often started in less than a minute from the time they entered after being marked, might be in any direction. There was no tendency, even if they had taken a single seed from a large pile of seeds, to return in the direction from which they had just come. For this reason there is little concentration of ants around a pile of seeds placed in a given locality; only those individuals which happen to blunder upon it take seeds. Nevertheless, there is a certain tendency for ants to go to a region in which there is a regular supply of seeds, as around the bird traps already mentioned, rather than to places where seeds are scarce.

In view of the facts presented above, the problem of how the ants find their way back to the nest becomes interesting, and in July, 1940, several experiments were performed in an attempt to determine the answer to this question. When an ant is given a seed, it almost invariably takes it and starts to go directly toward the nest. Therefore, by presenting an ant with a seed one can be quite certain of having given it a strong urge to go to the nest. This fact has been used extensively in these experiments.

On a number of occasions an ant returning to the nest with food was allowed to start to walk across a sheet of paper, and while on it was moved a considerable distance, often to a place on the other side of the nest. It was thus possible to transfer the ant without disturbing it to such a degree that its reactions could not be counted upon. Always, if the new location were within the area normally covered in foraging trips, the ant changed its direction and traveled toward the nest without hesitation from the new position. If a barrier, such as a board on edge, were placed on the ground between a returning ant and the nest, the ant would go around the board, showing evidence of seeing it when four or five inches away, and start directly toward the hole from the changed position. It is thus clear that the direction of light has little or nothing to do with the orientation of the ants, for if it did they would continue in their old direction when artificially transferred from place to place.

Several ants, either having seeds or given seeds after being moved, were transferred, as described above, to places about eighty feet away from the nest and well outside of the region in which the ants were in the habit of working. There, except as discussed below, they wandered erratically, still carrying their seeds. If after a few minutes they were returned to a point in the region where foraging ants normally work, they immediately went directly toward the nest opening. This suggests that they orient themselves by memory[6] of certain features of the region with which they are familiar.

Two of the individuals which were carried about eighty feet away were taken almost directly from the entrance of the nest and probably belonged to the large class of individuals which come out of the nest for only a few inches, then turn and go back into it. Given seeds, they took them, but soon put them down and explored the vicinity, each fre-

[6] Memory is here used in the sense of series of conditioned responses, that is, as differential behavior with respect to present stimuli as a result of previous experience with the same stimuli.

quently returning to its seed, from which it made progressively longer and longer trips so that in three minutes from the time they were given seeds the ants were going as far as one and one-half feet from their seeds. Brought back to the vicinity of the nest, they showed no facility in finding it. This is probably an indication of some sort of division of labor among the workers; possibly the younger ones work around the colony, only one older ones going out to collect food. It gives further evidence that memory[6] of the surroundings may be the means by which the ants find their way back to the nest.

On one occasion seeds were sprinkled in an area about fifteen feet from the nest. Then a band four feet in width between the seeds and the nest was cleared and the top half inch of soil removed so that its distinctive appearance and odor must have been totally changed. Ants which had gone out before this clearing was done found seeds and returned with them, without hesitation crossing the cleared area. This indicates that their ability to return directly to the nest is not dependent on characteristics of the odor of the surface of the ground or the appearance of the smaller objects on the ground, but may perhaps depend upon memory of large objects, such as bushes and the like, a number of feet away.

In order to test this idea further, the bottom ($3\frac{1}{2} \times 2\frac{1}{2}$ feet) of a rectangular, wire-screen cage (one-half inch mesh) was covered with paper and then with a thin layer of soil. The screen at the sides would cause little interference with vision and would permit ants in the cage to see possible landmarks outside. An ant, given a seed, was allowed to walk onto the bottom of the cage via an incline of dirt or was transferred to the cage on a piece of paper. It would start through the cage toward the nest. The cage was then lifted off the ground and turned through any angle. While still off the ground, the ant would change its direction with respect to the cage and continue toward the nest. It was impossible, even with repeated rotations, to cause the ant to lose its direction, and when finally the ant walked out of the cage, it continued to the nest. This experiment was repeated several times with different ants with similar results.

On the other hand, when the sides of the cage were covered with paper and the ends similarly covered except for the lower three inches (so that an ant inside could see only the unfamiliar bottom of the cage, the paper walls, small openings at the ends of the cage and the sky above), ants with seeds would continue toward the nest when first introduced into the cage. However, after one or two 90° or 180° turns of the cage, and not until such turns, they lost their direction, sometimes wandering irregularly, more often walking back and forth the length of the cage. If allowed to walk out under the paper walls, they immediately oriented themselves properly and went to the nest. This shows that no odor or sound emanating from the nest could guide the ants back to it, because the ants inside the cage with paper walls presumably would have perceived these as easily as those in the open cage or outside on the ground.

Finally, a number of ants found well away from the nest while apparently searching for food were picked up with a pair of forceps, and their eyes covered with thin flour paste or water putty, which dried to form a thick, opaque covering. After being held for a few minutes until the substance on the eyes dried, the ants were put down on the ground near where they were found. For five to fifteen minutes ants so treated acted very abnormally, running around irregularly, refusing to pick up seeds, and trying to scrape the covering off their eyes. After that period of read-

justment and struggling, they stopped at seeds offered them. Most refused to pick them up, but two did so and carried them about, wandering aimlessly. These ants were again picked up and the coverings chipped off their eyes. After a period of adjustment following handling similar to that described above, they accepted seeds offered them and carried them directly to the nest. As controls to this experiment, similar coverings were placed on parts of the body other than the eyes of several ants. After a period of adjustment following being picked up, they were able to carry seeds directly back to the nest. An ant with only one eye covered could find the nest satisfactorily.

These experiments seem to indicate that this species of ant is guided in its foraging excursions largely by its sight, presumably by its memory of rather large objects some distance from its line of travel, and not to any large degree by stimuli perceived through other receptors. Cole's[3] observations on nocturnal foraging, however, suggest that the ants may under some circumstances find their way without the use of much light. According to Forel and Wasmann, the antennal sensillae are the chief receptors of information concerning location and are of importance in the homing of many ants. Nevertheless, these authors state that certain ants make use of their eyes as well as their antennae in finding their way, and *Pogonomyrmex* appears to be an extreme case of specialization in this direction, perhaps resulting from the long association of species of the genus with windy deserts, where the aridity, shifting soils and widely scattered food supply make odor a poor guide. It is interesting to note that the eyes of workers of *P. californicus* are rather large for ants although smaller than those of *Formica*, and each consists of about three hundred ommatidia.

Summary

Observations on a colony of harvester ants (*Pogonomyrmex californicus*) in Pasadena, California, have shown that for three or four months during the winter the nest is continually closed and that during the remainder of the year it is closed every night. Outside activity goes on only during the warmer parts of the days. The actions of the ants are well correlated with temperature; they are sluggish at 70° F., exhibit maximum foraging activities with temperatures at the surface of the ground between 90° and 115° F., and are driven into the nest except for very brief excursions by temperatures over 120° F. Swarming occurs more than once each season, during the late mornings of certain clear, hot days in June and July. The introduced Argentine ant (*Iridomyrmex humilis*) is a serious pest of the *Pogonomyrmex*. Although the harvesters apparently perceive seeds, which are their chief food, through antennal sensillae, it appears likely that they are guided in their foraging excursions, notably in finding their way back to the nest, largely by the use of their eyes.

Note: The colony of harvester ants discussed in this paper did not open its nest in 1941, after a winter of rainfall far heavier than that experienced for many years and nearly twice the average. The same was true of certain other colonies in the region, one of which, according to the report of the owner of the property on which it was situated, was at least forty years old.

SCIENTIFIC RELATIONS BETWEEN EUROPE AND AMERICA IN THE EIGHTEENTH CENTURY

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THE American colonies were settled in an age which witnessed a tremendous growth of interest in science. Its utilitarian significance was immediately appreciated in a world that emphasized middle-class values. But, apart from its meaning for the advancement of business enterprise, science had its followers who looked to it for guidance in unearthing the secrets of the universe. It has largely been a joint enterprise from the seventeenth century on, and to the layman as much as to the academician in these early years is due the accumulation of masses of scientific and near-scientific data. To mention one instance, plans were made for English and American groups to make a cooperative study of vegetable colors, and in general to aid each other in the study of natural history.[1] In a retrospect of the eighteenth century, a writer in a popular magazine observed that an international scientific correspondence prevailed and that in the promotion of utilitarian devices "the world is but as one Family." "The scientific theorist and the practical labourer have shaken hands and minted into one common stock the result of their labours."[2]

Scientists began writing in the vernacular thus reaching a larger audience. Condorcet strongly urged the abandonment of Latin, and the number of books on natural history written in the classic tongue declined rapidly in the eighteenth century. In writing for the populace care was taken to avoid technical language and, when necessary, authors took pains to define even simple terms. One of the first great popular successes was Buffon's "L'Histoire Naturelle" which sold over twenty thousand copies and was to be found scattered over Europe and America.[3] Linnaeus was informed that books on natural history sold better than any others in England.[4] In America the more popular channels of scientific communications were the newspapers and the almanacs, the latter reaching an annual circulation of many thousands.[5] The magazines extracted articles from the *Philosophical Transactions* of the Royal Society and thus reached a vastly larger group. The Newbery publishing house, so famous for its children's books, saw to it that even very young readers were informed on physics, motion, water, fire, vision, etc. There must have been a keen demand for these publications, for some of them ran into several editions.[6]

Lectures were widely attended in America and Europe, with women as well as men in attendance. Dr. Henry Moyes was in America in the 1780's and

[1] J. E. Smith, "A Selection of the Correspondence of Linnaeus and Other Naturalists," London, 1821, Vol. 1, Dr. A. Garden to Charles Whitworth, April 27, 1757. Hereafter cited as Smith.

[2] *Gentleman's Magazine*, 1800, pp. 1273–74.

[3] D. Mornet, "Les Sciences de la Nature en France au xviiie Siécle," pp. 2–4, Third Part, Chap. I.

[4] Smith, Vol. I, April 16, 1747.

[5] See C. E. Jorgenson, *New England Quarterly*, 8: 555–561; on almanacs in Europe, see Preserved Smith, "A History of Modern Culture," Vol. 2, p. 391.

[6] Charles Welsh, "A Bookseller of the Last Century," p. 302. London: John Newbery, 1885.

it was reported from Philadelphia that "people of every description, men and women, flock to the lectures. They are held at the University three evenings a week."[7] In a work published for the use of school children the latter were advised to "make it a rule to see for [themselves]."[8]

Americans were to be found on the rolls of many European societies who welcomed contributions from overseas in the advancement of science. Europeans, on the other hand, considered it a great honor to be elected to membership in the American Philosophical Society.[9] Count Rumford, an exile from his native America after the Revolution, established medal awards by the Royal Society and the American Academy of Arts and Sciences for leading contributions in heat and light. He was, incidentally, the first winner of his own award in England.[10]

War itself was held to be no bar to an exchange of scientific communications between antagonists. Joseph Willard, writing from Harvard during the Revolutionary War to the secretary of the Royal Society, maintained that "political disputes should not prevent communications in matters of mere science"; he did not see how any one could "be injured by such an intercourse."[11] During the earlier war between the French and English, naturalists in both countries had an understanding to return specimens that had been captured by enemy warships.[12] The bitter conflict with the government of the French Directory did not prevent an English captain from extending courtesies to a scientist returning from America with a vast collection of plants, and he was permitted to run the blockade.[13]

In the large commercial warehouses were gathered goods from the ends of the earth, and here and there among the products of trade could be found curiosities—fossils, sea shells and what not—all calculated to provoke the imagination. Merchants stole time from more prosaic pursuits to write letters which transported them to distant realms. Peter Collinson, the London merchant and naturalist, writing to John Bartram, the Pennsylvania botanist, apologized for the repetition in some of his letters; "a multitude of affairs divert my memory, and my letters are not worth copying—being mostly writ behind the counter."[14] There were many of the type of Collinson who were included in the membership of the scientific societies then rapidly spreading over Europe. From the start these organizations revealed a cosmopolitan outlook. One of the earliest, established at Rome in 1600, had a plan to locate groups everywhere in the world for scientific cooperation. Among its publications was a "Thesaurus Mexicanus," a description of plants and animals in Mexico.[15] Other societies founded on Italian models followed their lead.

The most famous of these organizations was the Royal Society in England. Its influence was world-wide, and its publication, the *Philosophical Transactions*, was the most distinguished forum avail-

[7] William Darlington, "Memorials of John Bartram and Humphry Marshall." (Philadelphia, 1849.) Mary Norris to Marshall, February 23, 1875. Hereafter cited as Darlington.

[8] "Botanical Dialogues between Hortensia and her Four Children . . . for the Use of Schools." By a Lady (London, 1797), with a commendatory letter by Erasmus Darwin, p. 229.

[9] *Transactions of the Society . . . for the Encouragement of Arts, Manufactures and Commerce* (1789), Vol. 2, p. 361; *Cal. of Franklin Papers*, Vol. 2, J. Ingen Housz, Vienna, November 19, 1783, M. Defaÿ, January 12, 1784, Wm. Herschel, February 18, 1787.

[10] G. E. Ellis, "Memoir of Sir Benjamin Thompson, Count Rumford," pp. 241, 246, 250–258.

[11] *Philosophical Transactions*, Vol. 71, February 16, 1781; see also Franklin's letter to Alexander Small, Passy, July 22, 1780, in Smyth, "Benjamin Franklin, Writings."

[12] Smith, Vol. 1, "Ellis to Linnaeus," May 31, 1757.

[13] *Gentleman's Magazine*, 1798, p. 716.

[14] Darlington, p. 134 (September 2, 1739).

[15] M. Ornstein, "Scientific Societies in the 17th Century," pp. 74–76.

able to scientific opinion. The Royal Society sought information on the natural history and physical condition of foreign lands and to that end a correspondence with other societies was early established. This correspondence was read at the meetings, and it made the Society more of an international than a local English group; "every important experiment, every important article, was communicated to it almost as soon as it was published."[16] French, German and Russian societies were likewise established before the first quarter of the eighteenth century was over. Not until the second half of the century were similar organizations formed in English America, although many years earlier Increase Mather had gathered together with a small group fairly regularly to discuss philosophical problems and to add "to the Stores of Natural History."[17]

Although organized efforts in behalf of science came comparatively late in the colonies, individual initiative, in cooperation with European societies, made up for this lack. Secretary Oldenberg wrote to John Winthrop, the earliest American member of the Royal Society, when asking for communications: "You will please to remember that we have taken to taske the whole Universe, and that we were obliged to doe so by the nature of our Dessein. It will therefore be requisite that we purchase and entertain a commerce in all parts of the world with the most philosophicall and curious persons to be found everywhere." Four years earlier, Oldenberg had confidently written Winthrop that the Society expected from him a better description of "the remarkables (of New England) than is any yet extant, concerning the mappe of the country, the history of all its productions, and particularly of the subterraneous ones . . . likewise a relation of the Tides upon your coast, together with the course of your rivers, but especially and above all, a full account of your successe in your new way of salt-making, whereof we could not compasse the experement here, as was much desired." Oldenberg joined with Winthrop in ridiculing "the notional and disputaceous school philosophy" and urged him to foster "this reall Experimental way of acquiring knowledge, by conversing with, and searching into the works of God themselves"; the youth of New England should be "seasoned and possesse[d] with the same."[18] Oldenberg urged that a natural history of New England be written. Years later the grandson of Winthrop was honored by the dedication to him of a volume of the *Philosophical Transactions* for his numerous contributions to mineralogy.[19]

From the lips of Dutch merchants returned from Brazil to their native Amsterdam, a young German student, George Marcgrave, heard stories that aroused his curiosity so that he was given a place in an expedition to South America in 1638. Here he stayed for several years making observations of all kinds and gathering large collections of the fauna and flora of Brazil. Although he died before he could put his material in shape for publication, others took up the task. De Laet, of the West India Company edited some of Marcgrave's work which appeared in Leyden under the title, "A Natural History of Brazil." In this book appeared more than six hundred and fifty forms, nearly all new to science, some four hundred of them were figured from the drawings left by Marcgrave. When Count Maurice, leader of the expedition, returned to Holland, he brought back a collection

[16] Ornstein, pp. 124, 127; *Philosophical Transactions*, passim.

[17] K. B. Murdock, "Increase Mather," pp. 147–148. Cambridge, 1925.

[18] Massachusetts Historical Society, *Proceedings*, ser. 1, XVI, 211, October 13, 1667; August 5, 1663; March 26, 1670.

[19] Vol. 40; see long dedicatory notice to John Winthrop, F.R.S., August 15, 1741.

so rich in specimens that he had enough for his own museum and those of other private individuals, besides supplying two universities. By common consent of leading authorities, Marcgrave is accorded a high place for his contributions to ichthyology: he made known to scientists over one hundred new fish. Four charts of Brazil done by Marcgrave were etched on copper by the order of Count Maurice, and copies of these were to be seen on the walls of aristocratic Dutch homes.[20]

The comparatively few efforts of the seventeenth century were to be multiplied in the next, and systematic coordinated scientific activity in several fields may be noted. The contributions of American members, now a larger group, to the Royal Society's "Transactions" were continued, and among the most active of them was Cotton Mather.[21] Individuals of equal or lesser fame sent their communications abroad and the publications of several European societies paid tribute to American activity.

This energy was mainly expended in the field of natural science, with especial emphasis on botany. It is no mere coincidence that great progress should have been made in botany when a new floral world was revealed to the European investigator. The thousands of specimens, hitherto unaccounted for, stimulated students to remarkable efforts. What is one of the earliest books on North American plants appeared in 1635, by J. P. Cornut, "A History of Canadian Plants," describing those which had been brought back to Europe. Not long after, John Josselyn, the traveler in New England, described its native plants and other "rarities." Josselyn included a list of plants introduced by the English, and like other observers he noted that while some transplanted products fared worse in America the greater number were "bigger and better" in the colonies.[22] The observations and collections of John Banister, of Virginia, engaged as a missionary in 1680, were catalogued in the "History of Plants" by Ray, eight years later.

Contemporary with Banister, William Vernon of Cambridge University and Dr. David Kreig made a trip to Maryland for botanical specimens which eventually came into the possession of Hans Sloane. Vernon looked forward on his return to a weekly discussion of the new specimens with Sloane and some other cronies.[23] Mark Catesby stayed in several colonies for a number of years under the patronage of several noted botanists. He wrote frequently to his patrons, keeping them informed of his travels in "one of the Sweetest Countrys I ever saw" (South Carolina), and sent them large quantities of plants and seeds.[24] On his return in 1726 Catesby began work on his massive publication, celebrated by an eighteenth century historian as "the most splendid of its kind that England had ever produced."[25]

In the work of the leading botanists of this period may be traced the new world contributions. To professional botanists the period from 1694 to 1735 is known as the "Tournefortian Period" after the author of one of the most important

[20] E. W. Gudger, *Popular Science Monthly*, 81: 250, 1912.

[21] G. L. Kittredge, American Antiquarian Society, *Proc.*, Vol. 26, n.s., p. 23; Kittredge, *Colonial Society of Massachusetts, Publ.*, Vol. 14; Theo. Hornberger, "American Literature," Vol. 6.

[22] John Josselyn, "New Englands Rarities Discovered," . . . pp. 85, 90, London, 1672; F. Mood, *Colonial Society of Massachusetts, Publ.*, 28: 24*ff*.

[23] British Museum, Sloane mss., 4037, July 24, 1698.

[24] Royal Society Library, mss., Sherard Letters, Vol. 2; Catesby to Sherard, 163–185, May 5, 1722–January 10, 1724–25.

[25] Richard Pultney, *Historical and Biographical Sketches of the Progress of Botany in England* . . ., Vol. 2, Chap. 44, pp. 55–57, London, 1790. Other American contributions are mentioned in Vol. 2, pp. 276–278.

books in botany. While Tournefort's debt to investigators in North America was large, the obligations of Linnaeus, who gave his name to the next period in botanical science were far greater.[26]

At a meeting of the Royal Swedish Academy of Sciences, Linnaeus suggested that some one be sent to North America to collect seeds of plants which would "improve the Swedish husbandry, gardening, manufactures, arts and sciences." Peter Kalm, who was chosen for the task, not only published his travels, but raised many of the seeds he collected in his private garden, while others were cultivated in the Botanical Garden at Upsala. Linnaeus, in his "Species of Plants," carefully noted the findings of Kalm. He further enriched his knowledge by a visit to the collections of Sir Hans Sloane and Mark Catesby, much of which had been gathered in North America.[27] In all, Linnaeus described some two thousand plants, and animals to the hundreds from North America in his "Species of Plants" and "System of Nature."[28] After visiting a garden in Amsterdam, Linnaeus wrote to a friend: "We are all devoted to the love of exotic plants, especially those from America."[29] The heavy indebtedness of Linnaeus' "System of Nature" (in its last edition) to Dr. Alexander Garden of South Carolina, was noted by other scientists: "no name occurs there more frequently" said one authority.[30] From every part of the world new and rare discoveries are brought to your door, wrote Collinson to Linnaeus, "your agents bring you tribute from every quarter."[31]

Expeditions came over to America from Vienna and from Italy, but the most important was probably that of André Michaux sent over by the French government in 1785. Michaux traveled all over the country and sent back to France over sixty thousand living woody plants and many boxes of seeds. His publications too, were of the first importance in the literature of natural history.[32] Michaux worked in friendly rivalry with an Englishman, John Fraser, who was also in South Carolina seeking out plants and grasses useful to his homeland. Fraser returned home with thirty thousand dried specimens of plants, as well as some living plants, and a new grass for meadow land or pasture. He also wrote a book in which he acknowledged the important assistance given him by Thomas Walter, a local resident. Without books or learned collections of natural history, Walter, said Fraser, "made his descriptions with an accuracy that is allowed to be by no means inferior to the most eminent botanists in Europe."[33] It is worth noting that a study of foreign plants stimulated a closer examination of native products.[34]

While Linnaeus and other European students benefited directly by investigations of fellow countrymen traveling abroad, they also felt obligated to Americans with whom they corresponded. No American was held in higher esteem than the self-taught Quaker, John Bartram.

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[26] P. A. Rydberg, *N. Y. Botanical Garden Contribs.*, Vol. 4, No. 100.

[27] Catesby correspondence in Sherard letters in Royal Society Library, mss., Vol. 2, May 5, 1722, Dec. 9, 1722; see elaborate publication by Catesby, "The Natural History of Carolina, Florida and the Bahama Islands" (2 Vols. 1731–1743); Edward Edwards, "Lives of the Founders of the British Museum" (London, 1870, 2 Vols.), section on Sir Hans Sloane.

[28] Rydberg, *loc. cit.*: J. A. Allen, *Annals of New York Academy of Sciences*, Vol. 18.

[29] Smith, Vol. 2, to Albert Haller, May 1, 1737; see also Rydberg, *Science*, Vol. 26 (1907), pp. 66 *ff.*

[30] *Transactions* of the Linnaean Society (1791), Vol. 1, introductory discourse by J. E. Smith: also Smith, Vol. 1, Garden to Linnaeus, June 2, 1763. Garden was elected to Royal Society at Upsala.

[31] Smith, Vol. 1, April 10, 1755.

[32] F. Brendel, *Amer. Naturalist*, Vol. 13.

[33] John Fraser, "A Short History of the Agrostis Cornucopiae: or the new American Grass" . . . , pp. 3–5, London, 1789.

[34] *Cf. Memoires de l'Academie Royale des Sciences* (1701), p. 209.

He was wholly devoted to his researches, writing simply, "I love Natural History dearly." To an English correspondent he wrote, "I am often exposed to solitary and difficult travelling, beyond our inhabitants, and often under dangerous circumstances, in passing over rivers climbing over mountains and precipices, amongst the rattlesnakes, and often obliged to follow the track, or path of wild beasts, for my guide through the desolate and gloomy thickets."[35] All the first rate botanists in Europe were acquainted directly or indirectly with Bartram's work. In the letter just quoted, he also wrote: "To my friends Doctor Dillenius and M(ark) Catesby, I sent my observations on such things as will be proper materials to assist them in composing their fine histories, for which they promised me one of their books." Dr. J. J. Dillenius, professor of botany at Oxford, deferred printing his "History of Mosses," till he could see what Bartram, Clayton and John Mitchell might send from America.[36] John Frederick Gronovius of Leyden, then printing a new edition of one of his works, wrote to Bartram: "You shall find [therein] the names of all the minerals and fossils you ever had sent to me, with an encomium and thanks of all the benefits You have bestowed upon me."[37] Bartram urged Gronovius to write in English: "I can make but a poor hand of Latin."[38] Philip Miller, superintendent of the Chelsea Garden, whose "Dictionary of Gardening" was the best known work of its kind, and was used as a model for the first American book on the subject, was another who enriched his collections because of Bartram's activity. The Garden at Chelsea displayed many of the specimens sent over by Bartram who in turn received numerous contributions from Miller.[39] Through Collinson Bartram was employed by a number of patrons on an annual basis to furnish them with seeds and plants. In the 1750's he was supplying some fifteen patrons, including the Prince of Wales, at a charge of five guineas each. Of three hundred new American plants introduced into England after 1734 (down to 1776) Collinson was responsible for forty, most of which came from Bartram: two hundred or so were credited to Philip Miller, many of which had likewise been sent over by Bartram. The latter, it may be mentioned in passing, was one of the first to produce hybrid plants, then called "mules."[40]

Within less than half a century, said Catesby, America "has furnished England with a greater variety of trees than has been procured from all the other parts of the world for more than a thousand years past."[41] A society was formed in Edinburgh to import American seeds (subscribers to pay two guineas each) and to draw up a catalogue of American and Canadian plants and trees which could flourish in Britain: a correspondence was also to be maintained with Americans interested in botany.[42]

The work of others besides Bartram was gratefully remembered by European contemporaries. Cadwallader Colden's catalogue of plants found on his New York estate was published by Linnaeus in the transactions of the Academy of Sciences at Upsala. The proficiency of

[35] Darlington, Bartram to Collinson, April 23, 1746; May 26, 1742; see also letter of Lewis Morris to Collinson, *N. J. Hist. Soc. Coll.*, IV, May 24, 1742.

[36] See G. C. Druce, "The Dillenian Herbaria" . . . Oxford, 1907, and J. J. Dillenius, "Historia Muscorum," p. viii. London, 1768.

[37] Darlington, July 2, 1750.

[38] Gibson mss., IV, 21, Friends House, London.

[39] N. G. Brett-James, "The Life of Peter Collinson," pp. 108–109.

[40] Peter Collinson, mss. "Note Book," British Museum Natural History; Ernest Earnest, John and William Bartram, chap. 4, and page 38. Philadelphia, 1940.

[41] Catesby, "Hortus Europae Americanus" . . . preface. London, 1767.

[42] *Scots Magazine*, February, 1764, p. 83, August, 1765, p. 395.

his daughter, Jane Colden, attracted attention abroad. Peter Collinson wrote Linnaeus that she was the only woman he had heard of who was "scientifically skilful in the Linnaean system," and he recommended her example "to the ladies of every country."[43] The "Virginia Flora" published by Gronovius was based on observations made by Clayton, and a later edition included the work of Colden, Mitchell and Kalm as well. John Mitchell, of Virginia, was credited with important discoveries and his name was especially drawn to the attention of Linnaeus.[44] Mitchell was at work for a long time on a comprehensive natural and medical history of the colonies. It was a lonely effort for Americans widely scattered along the seacoast and in the back country, wanting in books and in stimulating companionship. They sought out one another and craved the stimulation of the European botanical fellowship.[45]

Humphry Marshall, a younger cousin of John Bartram, was also in correspondence with Europeans and his book on American trees and shrubs received the stamp of scientific approval by translations for foreign students. John C. Lettsom was interested in forming a group to subsidize Marshall for a year to gather specimens from American woods and mountains. He told Franklin he was already sponsoring a European naturalist then traveling through America.[46] Marshall's "Arbustum Americanum" (1785) was the first strictly American botanical work, written by a native American and printed in this country. It was republished in Germany where foresters believed that the more rapidly growing American trees, if transplanted, might augment the dwindling supply of German timber. Wangenheim, a critical student of American woods, planted on his estate in Thuringia, a section of forest land which he called "America."[47] William Bartram, son of John, was a skilled naturalist who knew how to portray in words and colors the phenomena he met with in his expeditions to the southern colonies. Sponsored by Dr. Fothergill, Bartram spent five years in these regions and sent collections and drawings to his English Maecenas.

This interest in natural history was not restricted to the scientifically elect; it was a fad in which nearly all classes of society satisfied the desire to collect things. Collinson wrote to Bartram: "There is a [great] spirit and love of [gardening and planting] amongst the nobility and gentry, and the pleasure and profit that attends it, will render it a lasting delight."[48] Some of the nobles who could afford it literally transplanted a bit of America to England. Collinson described the collection of Lord Petre, a patron of Bartram: "The trees and shrubs . . . are grown to great maturity. Last year Lord Petre planted out about ten thousand Americans . . . which make a very beautiful appearance. When I walk among [his nurseries] one cannot help thinking he is in North American thickets, there are such quantities."[49] Collinson's own garden was internationally famous and its rarities were shared with many botanists. His contagious enthusiasm awakened the love of gardening among many young men of means. In retrospect he once remarked, "I often stand with wonder and amazement when I view the incon-

[43] Darlington, p. 20; "Jane Colden," in N. Y. Botanical Garden Contribs., Vol. 4, no. 88; Smith, April 30, 1758; Smallwood, "Natural History and the American Mind," p. 92.

[44] Smith, Collinson to Linnaeus, Vol. 1, January 18, 1743–44; Vol. 2, Mitchell to Linnaeus, April 16, 1747; Smallwood, p. 123.

[45] John Nichols, "Literary Anecdotes of the Eighteenth Century," Vol. 1, p. 483 note. Dr. A. Garden to Dr. J. Parsons, May 5, 1755.

[46] Jared Sparks, "Franklin's Writings," Vol. 10, p. 267, August 14, 1786.

[47] Pennsylvania-German Society, *Proceedings*, 7: pp. 28–29.

[48] Darlington, April 24, 1751.

[49] Darlington, September 1, 1741.

ceivable variety of flowers, shrubs and trees now in our gardens, and what there were forty years ago."[50] Dr. John Fothergill wrote to Linnaeus, "Our Collinson taught me to love flowers, and who that shared his comradeship could do other than cultivate plants?" Bernard de Jussieu, professor of botany at the garden of the French king, told Dr. Thomas Bond, an American visitor, that he would feel at home among so many of his native plants which had been brought from America by the professor himself.[51] The Sloane Herbarium and the Herbarium of Joseph Banks (both of which were incorporated in the British Museum) were enriched by plants sent over by Bartram, Catesby, Mitchell, John Clayton and lesser botanical explorers.[52] Books and articles were written to give instructions on the proper methods to pack and send plants from America, and in the 1780's a magazine was established to display in natural colors the foreign specimens cultivated in England.[53] An English author, J. R. Forster, who felt that the work of Gronovius made other compilations unnecessary, nevertheless wrote his book for he thought that English readers should learn about American plants in their own language.[54]

Botanical studies expressed esthetic as well as utilitarian objectives. But husbandry was almost entirely a practical matter. The advances made in the seventeenth century, largely under Dutch influence, were as halting steps compared with the giant strides of the next one hundred years. The achievements of Bakewell, Townshend and Jethro Tull helped revolutionize agriculture, and societies for the dissemination of their views were familiar institutions in England and America. Americans shared with Englishmen in the awards given for improvements in agriculture and the mechanical arts by the London Society for the Encouragement of Arts, Manufactures and Commerce.[55] Postmasters in New York and Charlestown actively propagandized in behalf of the London society.[56] Italian reformers also followed American proposals for promoting agriculture.[57]

Arthur Young, editor of the "Annals of Agriculture," and chief preceptor of the new agriculture, had for his schoolroom America as well as the British Isles.[58] George Washington was an eager disciple, and the notes he assembled from Young's publication and Tull's "Horse-hoeing Husbandry" indicate his indebtedness. Young taught him soil conservation and sent to Washington English plows and various types of seeds. In his last annual message as President, Washington recommended the establishment of a board of agriculture to award premiums and assist generally

[50] L. W. Dillwyn, "Hortus Collinsonianus," Swansea, 1843. p. vii: N. G. Brett-James, *op-cit.*, pp. 106, 225.

[51] Darlington, February 20, 1739.

[52] E. Ray Lankester, ed., "The History of the Collections contained in the Natural History Departments of the British Museum," Vol. 1, pp. 81, 83, 140. London, 1904.

[53] J. C. Lettsom, "The Naturalist's and Traveller's Companion" (London, 1772), had a third edn., 1799: Wm. Curtis, *The Botanical Magazine* . . . in which . . . Foreign Plants . . . will be accurately represented in their natural Colours . . . (London, 1787); I looked through ten volumes of Curtis' publication which contains many American plants.

[54] J. R. Forster, "Flora Americae Septentrionalis, or a Catalogue of the Plants of North America . . . in their Different Uses, and the Authors who have Described and Figured them" (London, 1771).

[55] Wm. Bailey, "The Advancement of Arts, Manufactures, and Commerce, or Descriptions of the useful machines and models contained in the repository of the Society for the Encouragement of Arts, Manufactures and Commerce" . . . (London, 1772, Vol. 1).

[56] "American Letter Book 1773–1783," p. 24, Anthony Todd to Foxcroft and Finlay at N. Y., June 1, 1774. Ms. in General Post Office, London.

[57] "Opuscoli Scelti sulle scienze e sulle arti," tomo 10, p. 321, Milan, 1787.

[58] "Letters from . . . George Washington to Arthur Young," London, 1801, especially August 6, 1786.

in diffusing information on the latest improvements. This proposal clearly followed the example of the English Board of Agriculture and revealed once more the influence of Young and Sir John Sinclair.[59] Sinclair, president of the English Board of Agriculture and correspondent of Washington and other distinguished Americans, had proposed such a plan to embrace all Europe and the United States, and his hope was that scientific communications would be exchanged among the agricultural departments of every nation.[60] Rewards made up of a fund subscribed to by every country, were to be given to those making useful discoveries in "Rural Economy" as well as in medicine and the "Useful Arts." In addition to the immediate practical advantages for science and industry that Sinclair expected would result from this international correspondence, he hoped too, that it would promote the cause of peace.[61] Americans participated in the debates on the merits of various fertilizers that filled the pages of Young's publication. They were very enthusiastic (at least for a time) over the effect of plaster of Paris on rejuvenating their worn out fields. Americans acknowledged the superiority of English husbandry, but they too felt capable of aiding its progress, especially in the invention of agricultural machinery. News came to Young from Philadelphia of a machine for threshing and cleaning grain in one operation delivering six bushels an hour "fit for the miller."[62] Benjamin Gale of Connecticut was awarded a prize by the London Society for the Encouragement of Arts for his improvement of the drill-plow.[63] Jared Eliot, the best informed writer on agriculture in colonial America wrote his own "Essays" because American conditions were so different from those in the mother country that books for English farmers were of little use overseas. He complained too, of the clumsy apparatus devised by Tull for drilling, and immediately set to work to make a simpler and more efficient machine.[64] Eliot's "Essays" were known abroad where advanced agriculturists held them in admiration.[65] American apples already had a market in England where they were esteemed above the native product.[66]

Strikingly modern ideas were bandied about. A Parisian correspondent asked Franklin's opinion about a primitive incubator.[67] A Frenchman projected an incubator and a Scotsman anticipated present day horticulturists by suggesting the possibility of accelerating vegetation by electricity.[68] But it was an uphill struggle for the reformer. As in England, so in America, wrote one to Young, "prejudices in favor of antient modes are laid aside with difficulty."[69]

None of the phenomena of nature so stirred the European in America as did the sight of new birds and animals. No European commentary was complete without reference to the beauty of the humming bird or the fascinating horror of the rattlesnake. Poets rhapsodized over the humming bird and the mocking

[59] P. L. Haworth, "George Washington, Country Gentleman," Indianapolis, 1915, Chap. 5; "The Correspondence of Sir John Sinclair," Bart. (1831, 2 Vols.), p. xxiv, Vol. 1, p. 279.

[60] Young, *Annals of Agriculture*, Vol. 27 (1796), pp. 42–48.

[61] Sir John Sinclair, "Plan of an Agreement among the Powers in Europe, and the United States of America, for the Purpose of Rewarding Discoveries of General Benefit to Society" (London, 1795).

[62] *Annals of Agriculture*, Vol. xvii, pp. 206–207.

[63] *Cal. of Franklin Papers*, II, December 10, 1770.

[64] R. H. True, *Agricultural History*, October, 1928.

[65] Smyth, "Franklin's Writings," Vol. III, to Eliot, December 10, 1751.

[66] Darlington, Letter of Michael Collinson, February 25, 1773.

[67] *Cal. of Franklin Papers*, II, November 25, 1773.

[68] *London Magazine*, February, 1747; R. H. Fox, p. 69.

[69] *Annals of Agriculture*, Vol. xix, p. 245.

bird, and veracious witnesses testified to the power of the rattlesnake to charm the unwary. English and Scottish newspapers attested to the general curiosity about rattlesnakes and other American fauna. A Boston correspondent wrote to the Royal Society of a local frog as big as a "*Penny loaf,*" "which cries exactly like a *Bull.*"[70] John Bartram sent over to Fothergill large bull frogs and playfully suggested they be put in St. James Park pond where they "would surprise & divert all the adjacent inhabitants of London" but on second thought he believed Kew Gardens would be better as "being more private."[71]

Several correspondents sent to the Royal Society their descriptions of American moose, pigeons and whales. The Society wanted from Cotton Mather a study of the relationship of winds to the migration of pigeons. He was asked for additional information (with which he was always ready) about the "Mouse Deer": "what we have hitherto had," said the Society, "being very imperfect & not to be depended on."[72] On the subject of whales, Paul Dudley wrote with scientific understanding, but emphasized particularly their economic value: "I am Endeavouring after a short natural history of our whales," he told Dr. Jurin. Within a few months he sent a fascinating description of the spermaceti whale and the nature of ambergris.[73] An attractive publication by George Edwards, "A Natural History of uncommon Birds and of some other rare and undescribed Animals" (1743–1751) owed considerable to American students of ornithology: he was aided too, by observing live specimens in London. In another work Edwards spoke of the importation of large numbers of the painted finch, either for gifts or to be sold.[74]

It was regretted that no satisfactory description or collection of the fish and insects of America had been made and to answer that need "The American Oracle" by Samuel Stearns included a section on the animals of North America listing some one hundred and fifty birds.[75] For the more learned there were numerous articles on American phenomena in the Philosophical Transactions. Franklin had already asked John Bartram to do what he alone was best fitted to achieve . . . the writing of a "natural History of our country."[76] Benjamin S. Barton's writings on natural history were known abroad where special notice was taken of his observations on the connection between the migration of birds and seasonal changes.[77] Jefferson, then minister to France, helped educate the Count de Buffon in American natural history, and ordered specimens to be sent over from Virginia.[78]

Naturalists in Europe and America were deeply interested in the fossils discovered in the Ohio Valley, although half a century earlier Cotton Mather had sent to John Woodward, paleontologist and secretary of the Royal Society, bones and fossil teeth.[79] One supposition was that the huge animals arriving at the salt licks in a wet season "sank so deep as not to be able to rise out & the others out of Sympathy or some other Cause not being willing to leave their Com-

[70] Benj. Bullivant, January 15, 1697–98, Royal Society Library, mss., B.2, 46.

[71] Bartram mss. letters, November 28, 1769, British Museum of Natural History.

[72] Royal Society Library, mss., W.3, 77; W.3, 79, 1713; M.2, 35, June 21, 1714.

[73] Royal Society Library, mss., D.1, 80, October 3, 1724; D.1, 85, April 5, 1725.

[74] George Edwards, "Gleanings of Natural History" . . . , pp. 132–133. London, 1758.

[75] "The American Oracle," pp. 331–338; (London, 1791), see statement on the need for such a work, *European Mag.*, Vol. 12, p. 274.

[76] Darlington, January 9, 1769.

[77] *The Monthly Review, or Literary Journal*, enlarged series, Vol. 36, p. 351.

[78] "Jefferson's Writings" (Monticello edition), to A. Cary, January 7, 1786, December 23, 1786.

[79] F. E. Brasch, *Scientific Monthly*, Vol. 33 (1931), pp. 348–349.

panions in distress have shared the same fate."[80] George Croghan, the Indian trader sent to Collinson some fossil teeth, and a close examination was made by the distinguished anatomists John and William Hunter, of some bones sent to the Royal Society. It was concluded that they were not the bones of an elephant, as had been imagined, but of a different kind of animal.[81] On comparing the teeth sent over by Croghan with those from Asia and Africa, Collinson concluded they were "what is called Mammot's Teeth from Siberia."[82] Franklin made similar observations and then went on to note the fact that "elephants now inhabit naturally only hot countries, where there is no winter, and yet these remains are found in a winter country; which looks as if the earth had anciently been in another position, and the climates differently placed from what they are at present."[83] Jefferson was anxious that "very exact descriptions" be made of these finds but he warned against premature theorizing: "the moment a person forms a theory, his imagination sees, in every object, only the traits which favor that theory." More facts must be collected, he insisted, before theories could be advanced as to these fossil finds.[84]

Within a short time fossils were added to the geological division of the British Museum, and as was the fashion in popularizing science in the eighteenth century, books for the general public referred to these finds. Jedidiah Morse's "American Geography" noted Jefferson's observations that the skeleton indicated an animal much larger than an elephant.[85] Fossils as well as minerals and "curiosities" were exchanged between the Royal Museum at Copenhagen and Yale College, and a proposal was made by the Prince of Parma to swap specimens so that Italian and American museums might thereby be enriched.[86] The discovery of fossils opened up many questions, particularly of identification —whence had they come? The conflicts between the Rationalists and the old order were accented by this problem for it separated more sharply those who defended and those who attacked the tradition of Genesis.

A large part of the history of scientific interrelations between Europe and America in the latter half of the eighteenth century can be written around the personality of Benjamin Franklin. It is quite impossible to appreciate the amazing diversity of his contacts with science, and the confidence its students placed in him, unless one reads the thousands of letters written to him and by him. Individuals on both sides of the Atlantic refrained from publishing till he had criticized their work, and a writer was happy indeed could he send forth his book dedicated to Franklin. He was one of the most important channels through which Americans and Europeans kept abreast of each other's achievements. He saw to it that scientific instruments for Americans were made by the best English and Scottish manufacturers. He was better known abroad than at home, said the *Scots Magazine;* look in the foreign publica-

[80] Thomas Hutchins to Brigadier General Haldimand, Nov. 15, 1768, "Journal from Fort Pitt to the Mouth of the Ohio in the Year 1768," Brit. Mus. Add. mss., 21686 (f. 39–42).

[81] *Phil. Trans.*, 57, 464; 58, 34; *Memoires de L'Institut National de Sciences et Arts*, tome 2 (1796), pp. 1–23; *Stralsundisches Magazin*, 1768, pp. 179–189; other German and Italian publications referred to these fossils.

[82] Darlington, Collinson to Bartram, May 17, 1768.

[83] Smyth, Franklin to Croghan, August 5, 1767.

[84] H. F. Osborn, *Science*, new ser., 82, 533–538.

[85] E. Ray Lankester, *op. cit.*, pp. 200–201; Morse, p. 55 (1798, 3rd edn.); Wm. Guthrie, "A New Geographical Historical and Commercial Grammar . . . ," pp. 899–900, (1798, 17th edn.).

[86] Ezra Stiles, "Diary," February 7, 1787; *Penn. Mag. of Hist. and Biog.*, Vol. 28, Jefferson to Peale, June 5, 1796.

tions on electricity, it urged, where will be found on almost every page the terms Franklinism, Franklinist and the Franklinian system. He was, said one English biographer, the "American Newton."[87]

Collinson first made Franklin's name known to the English when he published in book form some of the letters his American correspondent had written on electricity. Within a few months, Collinson was writing in excited exaggeration: "All Europe is in agitation verifying electrical experiments on rods."[88] Franklin's experiments early commanded the attention of the curious everywhere, and for the better instruction of a non-English reading public translations of his writings were rapidly made. Supporters of his lightning rods were more numerous in America than in Europe, but during his stay abroad in the decade of the 70's, Franklin encouraged their wider adoption. From London he wrote to Professor Winthrop of Harvard, one of his firmest supporters, that he had answered the questions of Nevil Maskelyne, the Royal Astronomer, relating to lightning rods: "I have likewise given sets of directions for erecting them to several persons who desired it." "I purpose to follow your advice," he continued, "and draw up a more compleat instruction to workmen than I have yet given, to be inserted in the Magazines. St. Paul's Church is now guarded . . . and many gentlemen's houses round London are now furnished with conductors." Winthrop replied that he had spoken and written in advocacy of lightning rods: "they are now becoming pretty common among us."[89]

A pamphleteer was confident that Englishmen would rapidly take to conductors, but as the Revolution approached political passions divided scientists on this question.[90] A magazine recommended to the inhabitants of St. Bride's, London, Winthrop's letter criticizing the repair of a church steeple without using a conductor: "Philosophy, we fear, in vain lifts up her still and gentle voice, and unavailingly calls out across the Atlantic."[91] Jean Baptiste Le Roy urged the French to use the rods, and Franklin proudly noted that in Tuscany and in Venice they had been erected.[92] The Austrian Emperor put conductors upon gunpowder magazines as well as other structures, and that thunderous figure of the French Revolution, Robespierre, appears more prosaically in correspondence with Franklin asking advice, so that as a lawyer he might argue with intelligence the question of the legality of lightning rods. Voltaire's example in putting a rod on his own house reassured many of the timid.[93] In later years during his stay in France letters came to Franklin from all over Europe requesting advice in the construction of lightning rods.

Frederick E. Brasch has written on the close relations that existed between the Royal Society and its correspondents in the colonies who supplied some of the data basic to the structure of eighteenth century science. Newton, wrote Cotton Mather to the Society, was "the *perpetual Dictator* of the learned World."[94] Massachusetts seemed to the distant Londoners a field for research with especial promise. The earth and the seas and

[87] *Scots Mag.*, Vol. 45 (1783), pp. 174–176; same article in *European Mag. and London Rev.*, Vol. 3 (1783); *Gentleman's Mag.*, 60, 572.

[88] *Cal. of Franklin Papers*, Vol. 2, Sept. 27, 1752; *Phil. Trans.*, 47: 202–211, 289, 565–67.

[89] Mass. Hist. Soc., *Proc.*, Vol. 15, Franklin to Winthrop, June 6, 1770, October 26, 1770.

[90] Benjamin Wilson, "Considerations to prevent Lightening from doing Mischief" . . . (June 24, 1764), Brit. Mus. Add. mss. 30094 (f. 106), *ibid.*, (f. 238).

[91] *The Monthly Review or Literary Journal*, Vol. 42 (1770), pp. 199–210. London.

[92] Smyth, Franklin to Winthrop, July 25, 1773.

[93] *Cal. of Franklin Papers*, Vol. 2, January 29, 1777; Smyth, 1: 9, 104, 105.

[94] Royal Society Library mss., to Richard Waller, M.2.29 (letter 2).

the heavens too, were probed for their secrets. Franklin, half seriously, urged Sir William Herschel to come to America where skies were brighter and the chances for astronomical discoveries thus greater. In gratitude for his election to the American Philosophical Society, Herschel sent a catalogue of one thousand new nebulae and clusters of stars.[95] But long before Franklin, Americans were adding to the store of astronomical knowledge.

In the seventeenth century Thomas Brattle's observations on the comet of 1680 (Halley's comet) were made use of by Newton. Paul Dudley, whose contributions to the Royal Society were nearly always written in a truly scientific spirit sent a history of New England earthquakes.[96] Cadwallader Colden and James Alexander sent several observations of the "Eclipse of the first Satellite of Jupiter . . . in New York for determining the Longitude of that place." They had already determined its latitude.[97] Andrew Oliver, Jr., of Massachusetts, received an appreciative and critical response from Joseph Priestley to whom he had sent his "Essay on Comets."[98]

Probably the ablest scientist in America, and Newton's most distinguished disciple this side of the Atlantic was Professor John Winthrop, of Harvard. He contributed some eleven papers to the Royal Society and his studies ranged from seismological disturbances to observations on the transits of Venus in 1761 and 1769. One of his correspondents was James Bradley, astronomer royal, to whom Winthrop wrote modestly, but confidently, of his researches, leaving to him the decision to publish a work on comets.[99] David Rittenhouse, of Pennsylvania, added to the value of the cooperative studies of the transits of Venus in which English and French astronomers joined.[100] The volume published by the American Philosophical Society containing the papers on the transit of Venus was reviewed with enthusiasm in England, and American frankness and openness in giving full details of their research were commended as an example to "those European Astronomers, who are so very *shy* of giving particulars."[101] Franklin's explanation of the aurora borealis was hailed as one of the first to be based upon the "sound principles of reason and philosophy."[102]

Studies of wind and weather obviously had great usefulness in an age of sailing ships, and Americans joined enthusiastically in compiling the valuable data. Spurred on by the ailing Cotton Mather, Isaac Greenwood, then Hollis professor at Harvard, offered to send the Royal Society an annual meteorological account of New England. He proposed to send over accounts of eclipses, for he had good instruments, he wrote, and his advanced students would also aid him. Greenwood suggested that societies in London and Paris get extracts from the journals of sea voyages and reports from sailors on winds and weather: "it is not impossible that we should be able to make a probable Judgment of the Effect and Influence of the Wind upon the

[95] Sparks, "Franklin's Writings," Vol. 6, p. 569, Feb. 18, 1787.

[96] Royal Society Library mss., D.1, 94, November 13, 1727.

[97] Royal Society Library mss., Classified Papers, VIII, 1, 76, August 9, 1723.

[98] Mass. Hist. Soc., *Proc.*, 2nd ser., Vol. 3, pp. 13, 14, February 12, 1775.

[99] Royal Society Library, Bradley mss. 44 (f. 147) September 21, 1761; *ibid.*, 46 (f. 4) April 18, 1760 (f. 18), May 19, 1760; F. E. Brasch, "Newton's First Critical Disciple in the American Colonies—John Winthrop," in Sir Isaac Newton 1727–1927, History of Science Society.

[100] Rittenhouse's death was mourned abroad. He was America's greatest astronomer, said C. D. Ebeling, *Amerikanisches Magazin*, Vol. 1, Part 3, 1796, p. 165.

[101] *Gentleman's Magazine*, 41: 416–417.

[102] *London Review of English and Foreign Literature*, 11: 233–36.

Weather."[103] These joint observations were to lead to the composition of a history of the weather, a project which was apparently approved by the Society. A writer in the *Gentleman's Magazine* asked that Americans keep systematic tables of meteorological observations which might explain the manners, customs, diseases and "the fall of countries." Proper tribute was paid to the work of Dr. Lining, of Charlestown, in this field, but much more was hoped for, especially from college presidents in the colonies.[104] An international meteorological society founded at Mannheim, 1780, had members in nearly every European country, Greenland and the United States, whose observations were printed in many volumes.[105]

News of Thomas Godfrey's invention of the sea quadrant was sent to Halley from Philadelphia by James Logan. Thomas Pownall, once governor of Massachusetts, where he had learned much of value for North Atlantic navigation, contributed an important paper to the Society, "Hydraulic and Nautical Observations on the currents in the Atlantic ocean." Some of his information came from Franklin, and other sources were American shipping masters who, thought Pownall, were superior to European masters and thus made "shorter & better passages." Quoting Franklin, Pownall said the speed of Nantucket ships westward bound was nearly equal to that of voyages from America to England, provided they skirted the edge of the Gulf Stream.[106]

Near the end of the eighteenth century a German bibliographer compiled a list of contemporary British and American authors, many of whom had made contributions to scientific knowledge. It is a long list including some three hundred American names whose publications were found in individual volumes but more often in periodicals. The great and the humble are here, and standing together with their contemporaries across the sea they remind us once more of the international character of scientific fellowship.[107] Dr. Benjamin Rush of Philadelphia understood it so when he wrote to that thoughtful friend of America, Richard Price; "In science of every kind men should consider themselves as citizens of the whole world."[108]

[103] Royal Society Library mss., G.2.6, May 1, 1727; G.2.7, May 10, 1727; D.1, 8, May 10, 1729.

[104] *Gentleman's Magazine*, 20: 493–95.

[105] Florian Cajori, "The Early Mathematical Sciences in North and South America," p. 133.

[106] Royal Library Society mss., L.6.59, May 25, 1732; H. E. Gillingham, *Penn. Mag. of Hist. and Biog.*, Vol. 51; Royal Society Library mss., Letters and Papers, Decade VIII, 189.

[107] J. D. Reuss, "Alphabetical Register of all the authors actively living in Great Britain, Ireland and . . . North America, with a Catalogue of their publications." (Berlin, 1791–1803). Dates of publications 1770–1803.

[108] Massachusetts Historical Society, *Proc.*, 2nd ser., Vol. 17, April 22, 1786.

FATS AND OILS IN WARTIME

By T. SWANN HARDING

SENIOR INFORMATION SPECIALIST, U. S. DEPARTMENT OF AGRICULTURE

WAR with Japan has greatly affected our imports of fats and oils. Not counting petroleum oil and the so-called essential oils used in perfumes, there are more than eighteen hundred fats and oils, of which about thirty form an important factor in our peacetime life and are grim necessities in war.

Ordinarily we tend to think of fats as foods—lard, butter, oleomargarine, kitchen grease, and so on. We remember that one factor in the German collapse of 1918 was the low fat content of the civilian diet which deprived the people of valuable energy food and vitamins. To-day the existence of synthetic vitamins renders fats less indispensable in that respect.

But in war or at peace fats and oils are necessary not only for food but also for making soap, paint, varnish, printers' ink, linoleum, metal products, textiles, leather goods and glycerine. Certain oils are also necessary to act as special lubricants for high-speed motors and metal-turning lathes.

In war all these uses become more urgent than during peace. Fats and oils have primary importance as foods because they are of high caloric and energy-giving value. Not only the armed forces but also civilian workers under greater strain and on longer hours need more fats than usual. Fats and oils also carry certain of the important vitamins in solution in many foods and thus assume added importance.

Glycerine is important in the making of nitroglycerine and other explosives. In peacetime it is a byproduct of the soap industry, but in wartime soap becomes a byproduct of the glycerine industry. Incidentally, that is why we should not anticipate a shortage of soap, for we must have large quantities of glycerine both for ourselves and others of the United Nations.

In 1940 about ten billion pounds of fats and oils were used in the United States. Of this amount about six and one half billion pounds went into edible products, two billion were made into soap, another billion went into paints, varnishes, printing inks and linoleum products, while the remaining half billion pounds found a wide variety of industrial uses from making tinplate to use as special lubricants.

Most of these fats and oils were produced in the United States, but about fifteen per cent., or a billion and a half pounds, had to be imported from the Philippines, Africa, Argentina, Brazil, Dutch East Indies and Malaya. We usually produce about all the food fats we need, but we are one third short of producing domestically all the fats and oils we need for soap, we lack more than a third of producing all we need industrially, and half our paint and varnish oils have to be imported.

War in the Pacific has jeopardized two thirds of the fats and oils we usually import. Of course some fats and oils are interchangeable, but a few are all but indispensable. Coconut oil is the ingredient that makes most soaps lather freely. It can be replaced to some extent by palm-kernel oil from Africa or babassu nut oil from Brazil. Hence the composition of certain fats and oil products will have to be changed.

The most extensive cuts will come in our customary imports of a billion pounds of coconut oil, palm oil and tung oil, annually. This will affect the soap

and glycerine, protective coating, tinplate and textile industries especially. The Department of Agriculture, under its farm-production goals announced January 16, 1942, is seeking to stimulate domestic production to prevent shortages.

During 1941 prices were rising and stocks were being rapidly depleted by increasing demand. In 1941 we used about eleven billion pounds, and in 1942 we shall doubtless use eleven and a half billion pounds of fats and oils, domestically. Add to that from five to eight hundred million pounds to be shipped under the Lend-Lease Program and an additional two hundred million pounds for commercial exports, and you get a total domestic disappearance of twelve and a half billion pounds for 1942.

The original farm-production goals were announced on September 8, 1941, but Pearl Harbor changed all that. Under those goals we should have had a fats and oils deficit of over a billion pounds in 1942, so the new goals called for greater domestic production of fats and oils. Even if these goals are achieved our factory stocks will run only about a billion and a half pounds, which is at least a billion low.

These new goals call for the domestic production of 700 million pounds more oil from peanuts than in 1941, 1,100 million pounds more from soybeans, 600 million pounds more linseed oil from flaxseed, and then, if meat packers adopt new fat-trimming processes that have been suggested to them, we should get an additional 600 million pounds of lard. Butter production just about keeps pace with population increases and we are not in urgent need of any more butter in 1942.

It might be of interest to know what some of these fats and oils are and their principal uses. The following are those used mainly for edible purposes: Butter, lard, tallow, and palm-kernel, coconut, cottonseed, soybean, peanut, oleo, olive and babassu nut oils. The following are principally used in soap-making: Tallow and greases, coconut, palm, palm-kernel, olive and babassu nut oils.

Oils widely used in the paint, varnish, linoleum, oilcloth and printers' ink manufacture are linseed, tung, perilla, castor, soybean and rape oils. Both castor and rape oils are also in demand as special lubricants.

Of these oils we usually imported coconut oil and copra from the Philippines and palm oil from the Dutch East Indies and Malaya. Japan controls the supplies of perilla oil, and tung oil is largely a Chinese product. Alternative sources of supply for coconut oil and copra were the Dutch East Indies and certain other South Pacific Islands, as well as East Africa, from which we may still derive some. We have also obtained considerable palm oil from West Africa in the past.

Some substitutions can also be made. Considerable quantities of babassu and other palm-kernel oils contained in the nuts of tropical palms could be substituted for coconut oil and are actually available in tropical Latin America, but transport, labor and equipment shortages make them inaccessible to us. Brazilian castor and other oils are being imported in part to take the place of tung and perilla oils.

It seems most likely that our remaining supplies of palm and coconut oils will be used altogether in industrial rather than in edible products wherein soybean and peanut oils readily replace them. However, peanut and soybean oils can be used in soaps only with difficulty, due to technical factors, but simple hardening renders them immediately useful in foods. Domestic linseed oil will also take up the slack in drying oils as we increase its production.

Department of Agriculture programs covering increased 1942 production of

peanuts, soybeans and flaxseed for oil involve price support in all cases and loans on flaxseed in addition. Price ceilings were imposed on fats and oils late in 1941, and a 90-day-supply order was issued to prevent hoarding. Early in 1942 the Office of Price Administration raised the ceiling on cash lard prices. These rulings both tend to conserve supplies and to give incentive for additional production.

Even if the soybeans and peanuts for oil required are produced other difficulties must be surmounted. The problem with soybeans is to provide sufficient crushing facilities to process thirty million bushels more than the quantity normally processed in the Midwest. But there are ample crushing facilities in the South and the Southwest. It remains to be decided whether to ship the beans to the crushers or the crushing equipment to the beans, and the latter will probably prove more economical.

There is no processing-equipment problem with peanuts, but they are a little difficult to raise successfully. Furthermore, peanut picking machines are required and they cost about five hundred dollars each, priorities being involved. This is more than the average individual grower can afford to pay, so financial arrangements must be made, perhaps on a community basis, to provide the pickers.

In order to procure more long-staple cotton farmers have been urged to plant their full national acreage allotment of about 27½ million acres in 1942. As much as possible should be put into medium or longer staple varieties. A substantial increase in the production of cotton-seed oil should result from this, an increase of from 150 to 250 million pounds, depending upon the actual increase in the cotton crop itself over that of 1941.

The 1942 farm-production goals also call for slaughter of ten million more hogs in 1942 than in 1941. This increase, along with improved methods of cutting out the fat, should yield us an additional 300 million more pounds of lard. It is estimated, finally, that an additional 700 million pounds of fats and greases could be recovered by more careful conservation methods in homes and factories. A campaign for home grease conservation will soon get under way.

It certainly appears that we should be able easily to make up our fats and oils deficit by increased domestic production. We should even be able to enlarge our rather low permanent stocks. Both because of this and because glycerine is such an important by-product of the soap-making industry, it is ill-advised either to hoard soap or to attempt the kitchen manufacture of our own.

A preliminary survey made by the Department of Agriculture as of March 1 indicated that American farmers were planting a million more acres of soybeans for oil than the goals required, but plantings of peanuts for oil would be 1½ million acres short of the goal. Flax acreage was up 20 per cent. over 1941, but was still half a million acres short of the goal. Farmers were therefore urgently asked to increase their soybean acreage still further beyond their March intentions, because considerable substitution can be made among these vegetable-oil crops. That is the latest word at this writing.

BOOKS ON SCIENCE FOR LAYMEN

THE HARVARD BOOKS ON ASTRONOMY FOR THE LAYMAN[1]

NINE books covering the whole field of astronomy have been projected in this series, and four have already appeared. Since the authors are all members of the staff of the Harvard College Observatory, the little volumes are known as the Harvard Books on Astronomy. There has long been a need for books that would give the layman somewhat more than the extremely popular ones, and yet that were not as technical as the college texts or scientific papers. The Harvard Books occupy this intermediate place. They are up-to-date, and contain much material that has not before appeared in book form. Many new astronomical photographs are included among the abundant illustrations. Edited by Dr. Harlow Shapley, director of the Harvard College Observatory, and his associate, Dr. Bart J. Bok, these books will be welcomed not only by the laymen but also by all amateur astronomers, and they will be indispensable to teachers of astronomy.

EARTH, MOON AND PLANETS

In this little volume, Dr. Whipple tells the story of the planets and our satellite, the Moon. He discusses in non-technical language the physical conditions of the planets and their atmospheres, the possibility of life on other worlds than ours, and the theories for the origin and evolution of the solar system. The Moon is considered with regard to its probable origin, as well as the development of its craters, mountains and other features.

In this book on highly calendered paper are superb photographs of the planets made by E. C. Slipher, of Lowell Observatory, who has made the best planetary photographs ever secured. All the planets are shown—even some of the recent photographs of Mars made in 1939 by Slipher in South Africa. A unique feature of the book is The Planet Finder, which enables one to locate all the naked-eye planets in the sky from the present time to 1970.

BETWEEN THE PLANETS

Dr. Watson discusses all the celestial bodies in our solar system except the nine major planets and their satellites, these having been treated in Dr. Whipple's book. Dr. Watson tells the story of the asteroids or minor planets from the discovery of Ceres in 1801 down to the present time when nearly 1,500 are known. He describes the comets as to structure and orbits, explains how Jupiter captured his family of comets, and how comets disintegrate or waste away as they travel around the Sun.

An outstanding feature of the book is the treatment of meteors, meteorites and meteorite craters. Here we have the latest information regarding meteor showers in relation to disintegrated comets; the recent accurate determination of velocities of meteors and what these indicate as to the origin of meteors and their relation to the solar system. The principal meteorite craters are described, as well as the largest and most striking meteorites known. Instruction is given in the identification of meteorites.

THE STORY OF VARIABLE STARS

This book will be of great interest to the host of variable star observers throughout the world, for here we have a description of the technique of observation as well as an analysis of the present status of our knowledge of variable stars. The senior author is the dean of pro-

[1] *Earth, Moon and Planets.* Fred L. Whipple. Illustrated. vi + 293 pp. $2.50. October, 1941; *Between the Planets.* Fletcher G. Watson. Illustrated. v + 222 pp. $2.50. September, 1941; *The Story of Variable Stars.* Leon Campbell and Luigi Jacchia. Illustrated. v + 226 pp. $2.50. October, 1941; *The Milky Way.* Bart J. and Priscilla F. Bok. Illustrated. v + 204 pp. $2.50. September, 1941. The Blakiston Company.

fessional observers of this class of phenomena, and he has for many years been a leader in organizing, directing and inspiring the amateurs in phases of this work in which they can contribute something of value.

The discovery and development of the great astronomical yardstick, based upon the period-luminosity relation of the Cepheid variable stars, an epoch-making advance in astronomy, is here described in a fascinating manner. Another absorbing story is that of the Novae, the most spectacular stars in the sky.

The Milky Way

This book is a stimulating presentation in semi-popular form of the history and present status of our knowledge of the Milky Way Galaxy. We are taken on an imaginary journey of exploration through this great system of two hundred billion stars. The story is told of the unfolding of our comprehension of this vast lens-shaped aggregation of suns; how its nature and composition were determined; how its dimensions were measured; how it was found that the Sun was not at its center, but between thirty and thirty-five thousand light-years from the center; how it was determined that our Galaxy rotates as a system once in two hundred million years.

Besides the discussion of the myriads of component stars or suns, we have a treatment of the bright nebulae in the Galaxy and why they are bright, the dark nebulae and interstellar gas. And the age of the Milky Way is considered. Included in a pocket inside the back cover are two excellent large photographic charts, one showing the northern Milky Way and the other showing the southern Milky Way. A feature that will please many readers is the inclusion of portraits scattered throughout the book of thirty of the leading astronomers who have added to our knowledge of the Milky Way Galaxy.

Clyde Fisher

RABIES—ITS PREVENTION AND TREATMENT[1]

The mad dog has been one of the symbols of preventive medicine. The effect of the bite of a rabid animal, the slow incubation, the terrible disease in humans and the prevention through the work of Pasteur have been history-making both scientifically and in the public mind. Such an evident carrier as the dog could be better understood and more graphically represented than the mosquito or the louse or the flea.

Over the years certain deviations from the anticipated results in handling wounds and vaccination against rabies have puzzled health officers and laymen. Dr. Webster's book is a review of known experience to discover the gaps in our knowledge and to face them rather than to develop plausible explanations to quiet further inquiry. Like all biological phenomena there are variations in the way living things react upon each other. The virus of rabies has its own personal and family history, and so has the individual carrier and the human patient. Perhaps this is the reason why rabies statistics lie or seem to do so.

Deep bites *vs.* superficial bites, caustic wound treatment *vs.* milder measures, delayed vaccine *vs.* prompt treatment are analyzed statistically without giving a clear-cut picture of just what is to be expected from therapeutic measures. Critical experimental evidence of the efficacy of vaccine treatment is still lacking and offers a fruitful field for further observation. McKendrick's statistics are quoted to the effect that "if a person is bitten by a rabid dog and takes treatment, his chances of contracting rabies are no more than 1 in 77 and usually as low as 1 in 510."

Besides recommending further investigations it is concluded that "persons exposed to rabies should be given vaccine treatment with confidence that then there

[1] *Rabies.* Leslie T. Webster. Illustrated. vii + 168 pp. $1.25. March, 1942. The Macmillan Company.

is small likelihood of development of the disease."

Dr. Webster concludes his short but important book with definite recommendations as to some twelve groups of cases into one of which practically every case in a doctor's hand will fall.

The strongest impression I get from reading this book is that every effort, no matter how annoying it may be to individuals, should be made to eliminate "carrier" animals by killing or through prolonged quarantine or some other appropriate procedure.

RAY LYMAN WILBUR

AS SCIENCE SEES US[1]

PORTRAITS have been drawn of man from various points of view. He has been represented as a god, a devil, a saint, a sinner, a hero, a poltroon. His vices and virtues have been emphasized and exaggerated in a thousand ways. Professor Needham describes his as the loftiest branch on the tree of life. He shows him briefly against the perspective of the myriad kinds of living organisms that inhabit the earth.

The book consists of two major parts: I, Man in His Biological Aspects, and II, Society in Its Biological Aspects, each consisting of ten chapters. In Part I the author is on the ground he has traversed all his life. Its rich and varied materials are at his command. He sees in man the processes and the physical characteristics that are illustrated more simply in countless lower forms. As he says, "We and the animals have been a very long time on this earth together. We have developed together; and in the beginning of our individual lives we still travel for a time the same old embryonic highway; it is the main-traveled road of physical development, our branch of which leads up to the heights where a higher mental life begins. We travel a little farther at the end, and reach thus a field of greater freedom of action that is all our own."

In this first part, Dr. Needham shows why he has long been regarded as one of the greatest teachers in Cornell. He sees both the diversity and the unity of living organisms. In pointing out their interrelations he enriches man, the summit being the organization and functioning of the higher nervous system. He gives a bird's-eye view of the animal kingdom. He devotes a chapter to man's remote ancestry. He follows a discussion of the vertebrate plan with a brief description of the development of the human brain. He leads on to the problem of learning and to nature and nurture in the human species. The whole first part is clear, entertaining, informative and often inspiring. The illustrations by Mr. William D. Sargent are excellent.

In Part II on Society and Its Biological Aspects a more difficult field is entered, if for no other reason than that the analogies with lower forms of life are fewer and not so close. Such difficult subjects are discussed as instincts, reason, the role of instinct in human affairs, war in its biolgical aspects, government in its biological aspects and, finally, religion in its biological aspects. The author has made a valiant attempt to describe these various human activities as consequences of the biological characteristics of man. Naturally, he entered much new and strange territory, the exploration of a great part of which has hardly been begun. It is not to be expected that his discussion will win such general approval as will that of Part I. Yet it is thought-provoking, for it suggests relatively new approaches to the greatest problems of human society. To say that this part of the book has shortcomings is only to repeat what could justly be said about any other discussion of the great questions that are considered. To have attempted so difficult a task requires courage, and to have succeeded so well is praiseworthy.

F. R. MOULTON

[1] *About Ourselves.* James G. Needham. Illustrated. 276 pp. 1941. $3.00. The Jaques Cattell Press.

THE PROGRESS OF SCIENCE

SIR ISAAC NEWTON, 1642–1727

SOME seven miles south of Grantham in Lincolnshire lies the small village of Woolsthorpe. By going a mile or so beyond this tiny town, one may still see the farm which belonged to Newton's parents and may also visit the large stone house—and even the room—in which he was born. The event of his birth, the tercentenary of which is now being celebrated on both sides of the Atlantic, occurred on Christmas Day, 1642. Here in the quiet surroundings of Woolsthorpe the lad spent the first twelve years of his life. At the end of this period, while Oliver Cromwell was still Protector of England and science was just becoming the fashion of the day, the young boy was sent off to the "public" school in Grantham, where he spent the next five years.

Following this experience, came a brief attempt on the part of his mother—the father had died before the son's birth—to make a farmer of him. She and her brother, the Reverend W. Ayscough, a Trinity College man, were however wise enough to see that the interests of the young Newton lay along the line of kites, windmills, water wheels, sun dials—in short, that he was devoted to mechanics and mathematics.

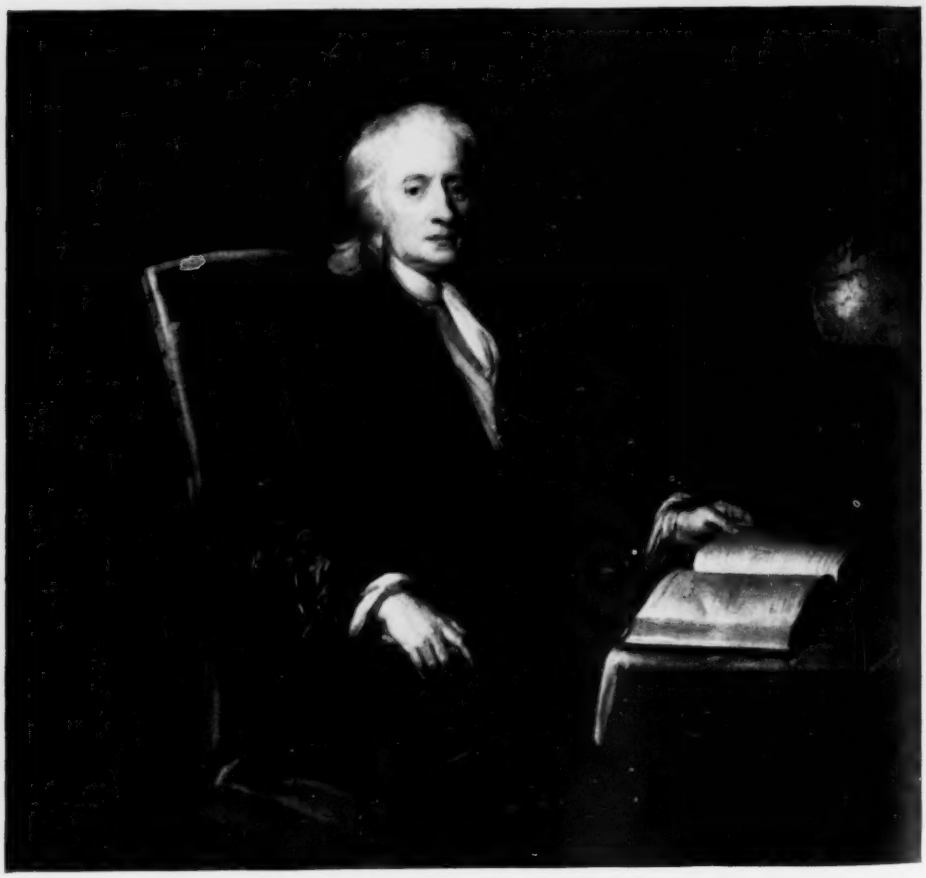
On the 5th of June, 1661, in his nineteenth year, he was admitted to Trinity College, Cambridge; and in 1665 was graduated B.A. Unfortunately, little is known about what subjects Newton pursued during these undergraduate years; even his class standing is unknown. Papers in Newton's handwriting show, however, that it was in this year that the first ideas of a differential calculus occurred to him. In the summer of 1665 the students of Trinity College were "forced from Cambridge by the plague." The same thing happened again in the following summer. Consequently, a long period of enforced leisure was enjoyed at his Woolsthorpe home. On the first of October, 1667, Trinity College elected him to a fellowship; and he again returned to Lincolnshire until the spring of the next year, when he received the Master of Arts degree. It was about this time that Dr. Isaac Barrow, distinguished mathematician and churchman, resigned the Lucasian professorship at Cambridge. To this chair, his pupil, Isaac Newton, now twenty-seven years of age, was promptly elected in 1669. The crowning honor for any young man —that of election to fellowship in the Royal Society of London—came on the 11th of January, 1672.

The key to such a rapid rise is doubtless to be found in the fact that, during two years of leisure at Woolsthorpe, this young mind had not only developed his invention of the calculus, but had also pondered over Kepler's laws and had wondered whether the curved orbit of the moon was not to be explained by the same force which makes a cannon ball take a curved path and an apple fall, from rest, in a straight line. The inverse square law had occured to other minds, as indicated in the "Principia" (Scholium to Prop. IV of Bk. I.); but Newton set about to verify the law by experiment and thus give it validity and acceptance. He knew fairly well the size of the earth; knew also that the distance of the apple from the attracting center was one radius of the earth, while the distance of the moon was sixty times as great. To obtain the ratio of the squares of these distances is a matter of the simplest arithmetic.

To compare the earth's attraction at the distance of the moon with that at the surface of the earth, Newton relied

upon the definition of force which, by universal experience and consent, makes it proportional to the acceleration produced. The problem is then reduced to a comparison of the distance which an apple falls from rest in one second with the distance which the moon falls away from the straight line tangent to its orbit in one second. But the ratio of these two accelerations did not agree as closely as he had hoped with the ratio of the inverse squared distances. Two uncertainties lingered in his mind: one as to the size of the earth; the other as to whether a sphere, such as the earth, attracts as if its entire mass were concentrated at its center. The first of these doubts was removed by the measures of Picard (1672): the second by a theorem of his own, proving, by his method of fluxions, that any solid sphere, in which the density is uniform over each concentric shell, attracts as if its mass were all at the center. The result was that the law of inverse squares was rendered highly probable.

A few years later this law was firmly established when Newton showed, again by use of his calculus, that, given two spheres attracting each other according to the inverse square law, the orbit of either body about their common center



ISAAC NEWTON, 1642–1727

FROM A PAINTING BY J. VANDERBANK IN THE NATIONAL PORTRAIT GALLERY, LONDON.

THE HOUSE IN WHICH NEWTON WAS BORN
NEAR THE VILLAGE OF WOOLSTHORPE IN LINCOLNSHIRE ON CHRISTMAS DAY, 1642.

of gravity must be a conic. The great paper containing this research was presented to the Royal Society on the 28th of April, 1686.

We are still considering the use which Newton made of his leisure at Woolsthorpe during the years 1665–66. Among his purchases during this period, one finds listed in his note book certain prisms, lenses, drills, putty, "glass bubbles," betraying his early interest in light and in the explanation of color. It is also significant that when, in 1669, he entered upon the duties of the Lucasian chair the subject which he chose for his lectures was optics. A memorable paper containing the outcome of these early optical experiments was presented to the Royal Society on the 8th of February, 1672, approximately one month after his election. A few sentences from this paper will illustrate the manner in which he disposes of the hitherto diverse and fantastic notions concerning color.

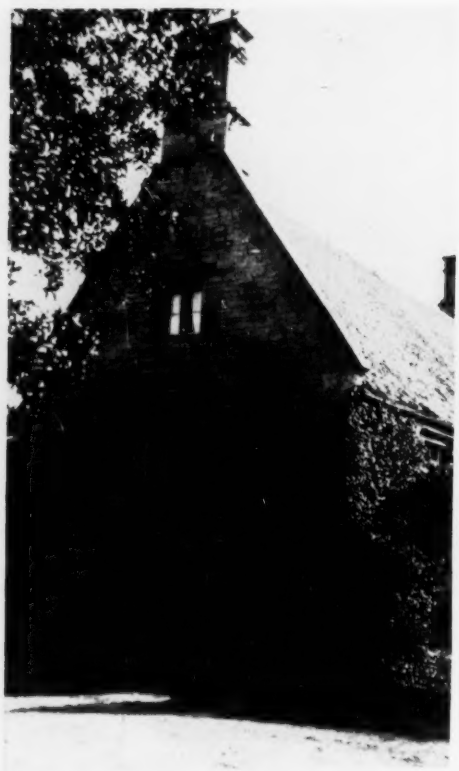
> Colours are not qualifications of light, derived from Refractions or Reflections of natural Bodies (as is generally believed) but *original and connate properties*. . . . To the same degree of Refrangibility ever belongs the same colour, and to the same colour ever belongs the same degree of Refrangibility. . . . The species of colour and degree of Refrangibility proper to any particular sort of Rays is not mutable by Refraction nor by Reflection from natural bodies nor by any other cause that I could yet observe.

Looking back over the four years that intervened between his graduation from Trinity College and his appointment to a professorship, one observes that the three outstanding achievements of his life were fairly initiated during this quadrennium. These were as follows:

1. The invention of the calculus—an

honor which Newton shares with the German mathematician and philosopher, G. W. Leibniz (1646–1716). Oddly enough the first printed account of the Method of Fluxions, as it was then called, is to be found in Wallis's "Algebra," pp. 390–396, which appeared in 1693: and then only because some of Newton's friends in Holland had informed him that, on the continent, the "Method of Fluxions" was becoming known as "Leibniz's Calculus."

2. The idea that the moon and the planets are held in their respective orbits by an attractive force varying inversely as the square of the distance from the central body. The mathematical proof of this theorem—presented to the Royal Society on 28th April, 1686—became the basis of the "Principia."



NEWTON'S BIRTHPLACE
THE TRIPLE WINDOW ON THE SECOND FLOOR LIGHTS THE ROOM IN WHICH NEWTON WAS BORN.

3. The simple theory of spectral colors, experimentally established in his youth—together with some later discoveries in interference and diffraction. These first came to light in his "Opticks," published in 1704.

From the preceding, it is clear that this young man at the age of thirty had definitely outlined three monumental contributions to human knowledge, had been elected fellow of Trinity College as well as fellow of the Royal Society and was now filling the leading chair of science at Cambridge University. Among the multitudinous activities of his later life, none exceeds in importance the publication of the "Principia—The Mathematical Principles of Natural Philosophy"—in 1687. Here we owe much to the astronomer, Edmund Halley[1] (1656–1742), who, having come to believe in the inverse square law, went to Cambridge especially to visit Newton in August of 1684. Halley put to Newton this question, "What will be the curve described by a planet round the sun on the assumption that the sun's force diminishes as the square of the distance increases?" To this Newton promptly answered, "an ellipse." When asked for his reason, his reply was, "I have computed it." Halley then secured a promise from Newton to send this demonstration to the Royal Society for record. The promise was fulfilled in February of 1685. The paper carried the title "De Motu." Its four theorems and seven problems proved to be identical with some of the most important parts of the "Principia." We owe still more to Halley; because the Royal Society thrust upon him the responsibility of printing this great work, but gave him no funds to meet the expense. However Halley's brain was not only nimble enough to appreciate the difference between thinking that the moon's motion was consistent with the inverse square law and proving that the orbit of the

[1] An account of the life and work of Halley will appear in an early issue of THE SCIENTIFIC MONTHLY.

moon must be a conic, but he was also generous enough to see the "Principia" through the press. The first edition was practically exhausted within four years of its publication; and a second edition did not appear until 1713. First published in Latin, the one language then understood by men of science in all the countries of Europe, the "Principia" became available to many students in England and in America only after 1729, when it was translated into English by Andrew Motte. It is this edition which the late Professor Cajori has revised and enriched with a scholarly fifty-page appendix. The simple elegance of this volume leaves nothing to be desired. On turning its pages one's only regret is that the pioneer who invented the calculus did not have the courage and wisdom to employ it here in his own book.

In the 382 pages of the "Opticks" (third edition, 1721), which first appeared in 1704, Newton thoroughly established the nature of spectral colors, the interference of thin plates, the phenomena of inflexion and the periodicity inherent in every ray of light.

Twice between the appearance of the "Principia" and the "Opticks" Newton represented Cambridge University in Parliament; but it does not appear that he ever took any very active part in the proceedings.

About this same time, early in the reign of William and Mary, Newton received another governmental appointment of considerable importance. The coinage of England had, since the Restoration, fallen into such a bad condition (owing to clipping and other mutilations) that a large percentage of it was refused acceptance in the payment of taxes. So when Charles Montague was appointed Chancellor of the Exchequer he shortly afterward invited Newton to become Warden of the Mint. In this position the author of the "Principia" ably directed the recoinage of the entire

Deutsches Museum.

CHRISTIAN HUYGENS

DUTCH MATHEMATICIAN AND ASTRONOMER, CONTEMPORARY AND FRIEND OF NEWTON.

metallic currency of England. In 1697, he was appointed to a still more important post, that of Master of the Mint. During all this while, he retained his Lucasian professorship at Cambridge; and it was only after occupying it for thirty-two years that he resigned it in December of 1701 and at the same time his fellowship in Trinity College.

English citizens generally consider the presidency of the Royal Society to be the highest honor which any British man of science can receive. It was in November of 1703 that Newton was elected to this post and annually reelected until his death in 1727. Knighthood came to him in April of 1705, when Queen Anne held court in Trinity Lodge at Cambridge.

The professional student will seek the acquaintance of Newton through the "Principia": but the layman will find a shorter and happier route through the reading of Bernard Shaw's recent play, "In Good King Charles's Golden Days." Here, in the first act, this accurate Irish scholar brings on to the stage (set for the

drawing room in Newton's London house) the following persons in addition to Sir Isaac himself: King Charles II; Godfrey Kneller, the portrait-painter; the Duke of York, later James II; George Fox, the Quaker; Nell Gwynn; Barbara Villiers; Mrs. Basham, Newton's housekeeper, and Sally, the housemaid. Far from being a romance, the play is one in which Shaw, with penetrating knowledge and marvelous skill, makes each reader personally acquainted with the historical characters represented by the *dramatis personae*. Space permits of only a brief sample of the conversation.

CHARLES. We must not waste any more of Mr. Newton's time, Mistress Gwynne. He is at work on fluxions.

NELLY. On What?

CHARLES. Fluxions I think you said, Mr. Newton.

NELLY. What are fluxions?

CHARLES. Mr. Newton will tell you. I should be glad to know, myself.

NEWTON. Fluxions, Madam, are the rates of change of continuously varying quantities.

NELLY. I must go home and think about that, Mr. Philosopher.

NEWTON. [*very seriously*] I shall be much indebted to you, Madam, if you will communicate to me the result of your reflections. The truth is, I am not quite satisfied that my method —or perhaps I had better say the notation of my method—is the easiest that can be devised. On that account I have never dared to publish it.

NELLY. You really think I could teach you something, Mr. Newton? What a compliment! Did you hear that, Rowley darling?

NEWTON. In these very simple matters one may learn from any one. And you, Madam, must have very remarkable mental powers. You repeat long parts from memory in the theater. I could not do that.

NELLY. Bless me, so I do, Mr. Newton. You are the first man I ever met who did not think an actress must be an ignorant ninny—except schoolboys, who think she is a goddess. I declare you are the wisest man in England, and the kindest.

CHARLES. And the busiest, Nelly. Come. He has given us as much of his time as we have any right to ask for.

Here must be left the story of the man whose laws of physics are employed in the design of every motor car, every airplane, every Diesel locomotive, every safe railway bridge.

HENRY CREW

DEVELOPMENT OF THE BETATRON

WITH the production of very high energy electron beams in the betatron or induction accelerator should come new applications of electrons to various practical problems as well as to problems of interest to the physicist. Already the betatron's energy has been extended sufficiently for one of the most promising practical applications. This is the therapy of deep malignant tissue by a penetrating electron beam. For this purpose electrons from the betatron must be capable of penetrating to the center of the human body. The ionization in the path of the beam produces the same destructive effect as the ionization from high voltage x-rays, which are now used in deep therapy. The disadvantage of the x-ray method is that the rays penetrate completely through the body and thus produce damage throughout. However, 20 million volt electrons, which the betatron now produces, penetrate at the most ten centimeters of tissue, and, in general, should produce—according to the estimates of Dr. Phillip Morrison—a maximum ionization effect about two or three centimeters from the end of their range; that is, in the case of 20 million volt electrons, seven or eight centimeters beneath the entrance surface of the body. This means that by choosing the proper voltage for the electron beam the maximum ionization and consequently the maximum damage could be localized on the malignant tissue. A 25 or 30 million volt betatron would be the ideal size for this work.

Although a fraction of the electron beam now escapes from the betatron by

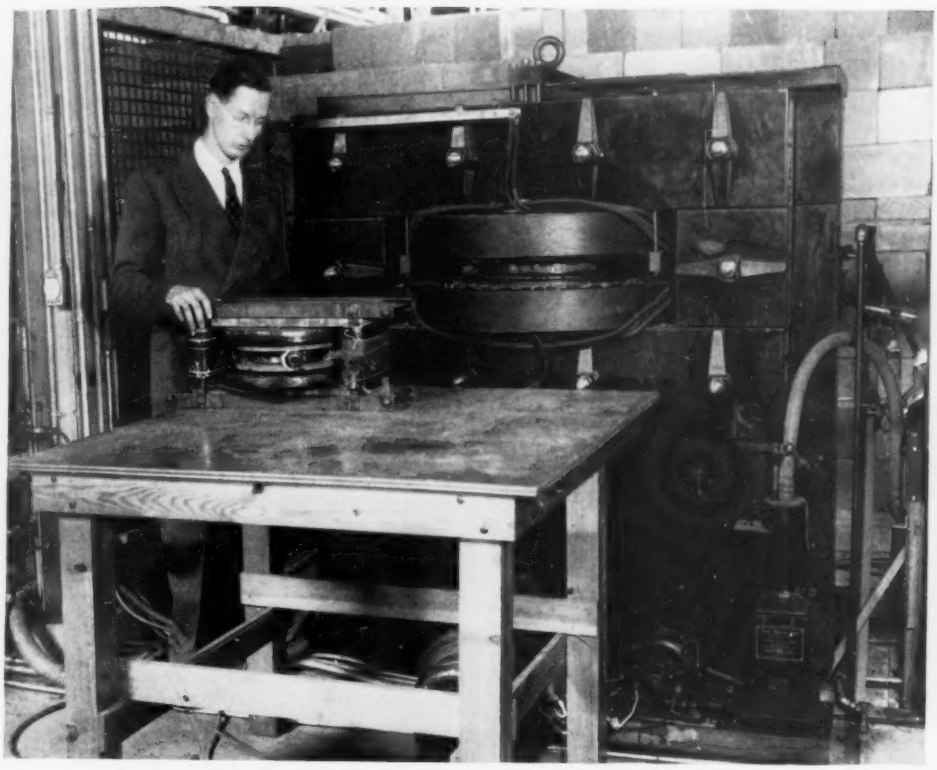


FIG. 1. THE OLD AND THE NEW BETATRON

THE AUTHOR WITH THE TWO INDUCTION ACCELERATORS, OR BETATRONS; THE ORIGINAL 2.3 MILLION-VOLT BETATRON IS SHOWN ON THE TABLE IN FRONT OF THE NEW 20 MILLION-VOLT BETATRON.

scattering off of the x-ray target, the ideal arrangement will be to withdraw the beam from the accelerator, as positive ion beams are now withdrawn from the cyclotron, so that the rays will be more homogeneous and less divergent. This development is a matter of time.

Perhaps the most important improvement in the induction accelerator which has come in the last year is one of flexibility of output energy. It is now possible to direct the accelerating electrons against the x-ray target at any stage of their acceleration. Electrons leaving a gun or injector when the magnetic field is very small circulate about the doughnut-shaped vacuum tube and are sped up by the increasing flux linkage produced within the orbit by the alternating current magnet. The voltage gain per revolution is the voltage which would be read on a volt-meter connected to one turn of wire at the position of the orbit. The electrons make as many as 200,000 revolutions, while the magnetic field increases from a very small value to its peak value.[1]

The energy of the original betatron, which was designed and built at the University of Illinois, was fixed at 2.3 million volts by the onset of saturation effects in the iron which brought the orbit in to a target. By eliminating the saturable material and electromagnetically expanding the electron orbit with a pulse of flux this betatron's energy be-

[1] D. W. Kerst, *Phys. Rev.*, 60: 47, 1941; D. W. Kerst and R. Serber, *Phys. Rev.*, 60: 53, 1941.

came easily adjustable to any voltage up to three million volts by controlling the time in the cycle at which the surge of flux expanded the orbit. This development was undertaken for application to the 20-million-volt betatron which has been constructed at the General Electric Works during a leave of absence from the university.

A further comparison of the two accelerators, which are shown side by side in the University Power Plant (Fig. 1), will indicate some of the changes. The small accelerator weighs approximately 200 pounds and has an eight-inch diameter pole face. The large model weighs about three and one-half tons and has a nineteen-inch diameter pole face. One million volts per inch of pole face diameter can be obtained.

The frequency at which the small magnet resonated was 600 cycles per second. This gave approximately 20 volts per revolution to the electrons, and the electrons were injected at an optimum of about 1,500 volts. The larger accelerator operates at 180 cycles per second, where the cooling problem can be easily handled by forced air cooling. The electrons gain a peak of 66 volts per revolution, and are injected at 15 to 20 kilovolts for a very brief time. Since the electrons have approximately the velocity of light, they travel 85 miles in the small accelerator and 260 miles in the large accelerator. The presence of residual gas in the vacuum "doughnut" hinders the electrons by scattering them only when the velocity is low.

Theoretically, the x-ray output of an induction accelerator should increase with the frequency at which the magnet operates. For one thing, the "doughnut" is charged with electrons more frequently and also, since the voltage gain per revolution increases with the frequency, the electrons can be injected at a higher voltage and at this higher

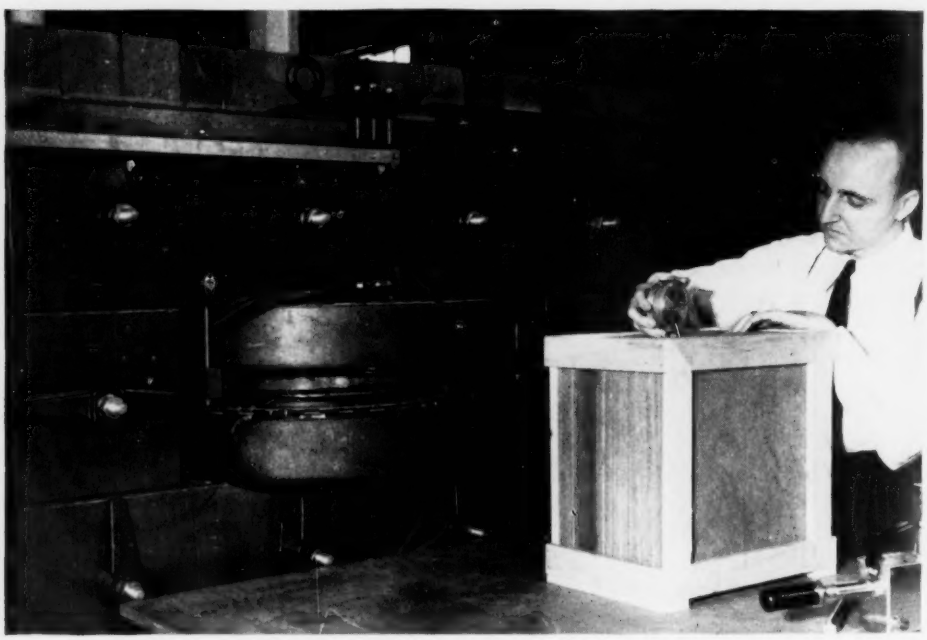


FIG. 2. APPARATUS FOR DETERMINING THE IONIZATION DISTRIBUTION USED IN THICK SECTIONS OF MATERIAL SIMILAR TO TISSUE.

injection voltage the orbit can hold more electrons against space charge forces. Currents of the order of .01 of a microampere are estimated to strike the target in the small betatron, while the current against the target of the large betatron is about one microampere. However, the rotating electron stream within the large accelerator is probably about 5 amperes. The small betatron required 5 kilowatts of power input while the large betatron takes 25 kilowatts. Recently we have made 60 cycle trials where the power consumption is 3 kilowatts at 20 million volts and the apparatus can be run from the wall outlet.

The fine beam of electrons which circulates in the betatron would be very useful if it could be drawn out of the betatron without much spreading. Such a beam drawn out from a relatively low energy betatron would be useful in an electron microscope where high energy allows thick specimens with small scattering and high resolution. The beam could also be used in other electronic instruments where a compact source of high-speed particles is desirable. Actual tests on the beam size can be made by examining the focal spot on the x-ray target within the induction accelerator. Tests with the small betatron showed that the spot struck by the electrons was less than one millimeter long.

Not only are the primary electrons of possible therapeutic usefulness, but also the very high energy x-rays which can be produced by these electrons may prove useful as a result of the improved distribution of ionization intensity which they will produce within the body (Fig. 2). This distribution of ionization is different from that found with x-rays having an energy an order of magnitude smaller since at 20 million electron volts the secondary electrons which x-rays produce within the body can have ranges comparable with the dimensions of the body. For example, the most energetic Compton electron produced by these x-rays would penetrate 10 centimeters. This large range means that the number of secondary electrons, and hence the amount of ionization reaching a location below but near the surface of the body, is proportional to the amount of tissue which is producing these secondary electrons between the location and the surface of the body. This means that for a certain distance the ionization will increase with depth below the surface. Unfortunately, many of the Compton electrons do not travel straight forward and hence their ionization effect is not carried as deeply into the body as it would be if these electrons, like primary electrons from the betatron, went in one direction. It was in the expectation that the betatron would be developed for general use in these important practical lines and in a compact and convenient form that the details and some of the development of the betatron were taken to an industrial organization.

Among the subjects of interest to the physicist which the betatron opens are the nuclear photo-effect and the study of the interaction of electrons and photons with matter. On the average six to eight million volts are required to remove a neutron from a nucleus of the elements. This neutron can be removed by a photodisintegration process in which a high energy x-ray or photon striking the nucleus ejects the neutron. The residual nucleus will be either a radioactive substance or a stable isotope of the original element. In either case neutrons have been produced. Important things which can be learned are the exact threshold energy at which this photodisintegration of each nucleus sets in, and information about the masses of similar nuclei can be found. The neutrons which are produced in this process will have energies determined by the threshold for photodisintegration and the betatron energy, and thus a

source of neutrons of variable energy is available.

Since the high-energy electrons which have previously been available for experiments come either from cosmic rays, in which case their energy is much higher than 20 million electron volts, or from radioactive substances which give a maximum of 12 million electron volts energy, the betatron furnishes electrons of adjustable energy in a new energy region where the behavior of electrons in penetrating matter, producing radiation and producing positive and negative electron pairs has not been examined. These problems, together with new ones arising in higher energy regions, appeared open to attack by the betatron from the time of the first operation of the small 2.3 million electron volt model. The purpose of our subsequent development was to extend the energy available in our physics laboratory with an induction accelerator following our 100 million electron volt design so that effects in the lower cosmic ray energy range could be studied.

D. W. KERST

NATIVES OF THE ALEUTIAN ISLANDS

THE natives of the desolate, fog-bound Aleutian Islands are not, strictly speaking Eskimos or Indians, although they show unmistakable signs of basic relationship to both these stocks, according to Dr. Hrdlička, anthropologist of the Smithsonian Institution. Only during the past decade has much scientific study been devoted to their origin, and to the history of their bleak habitat before its discovery by Vitus Bering and Chirikov, in 1741.

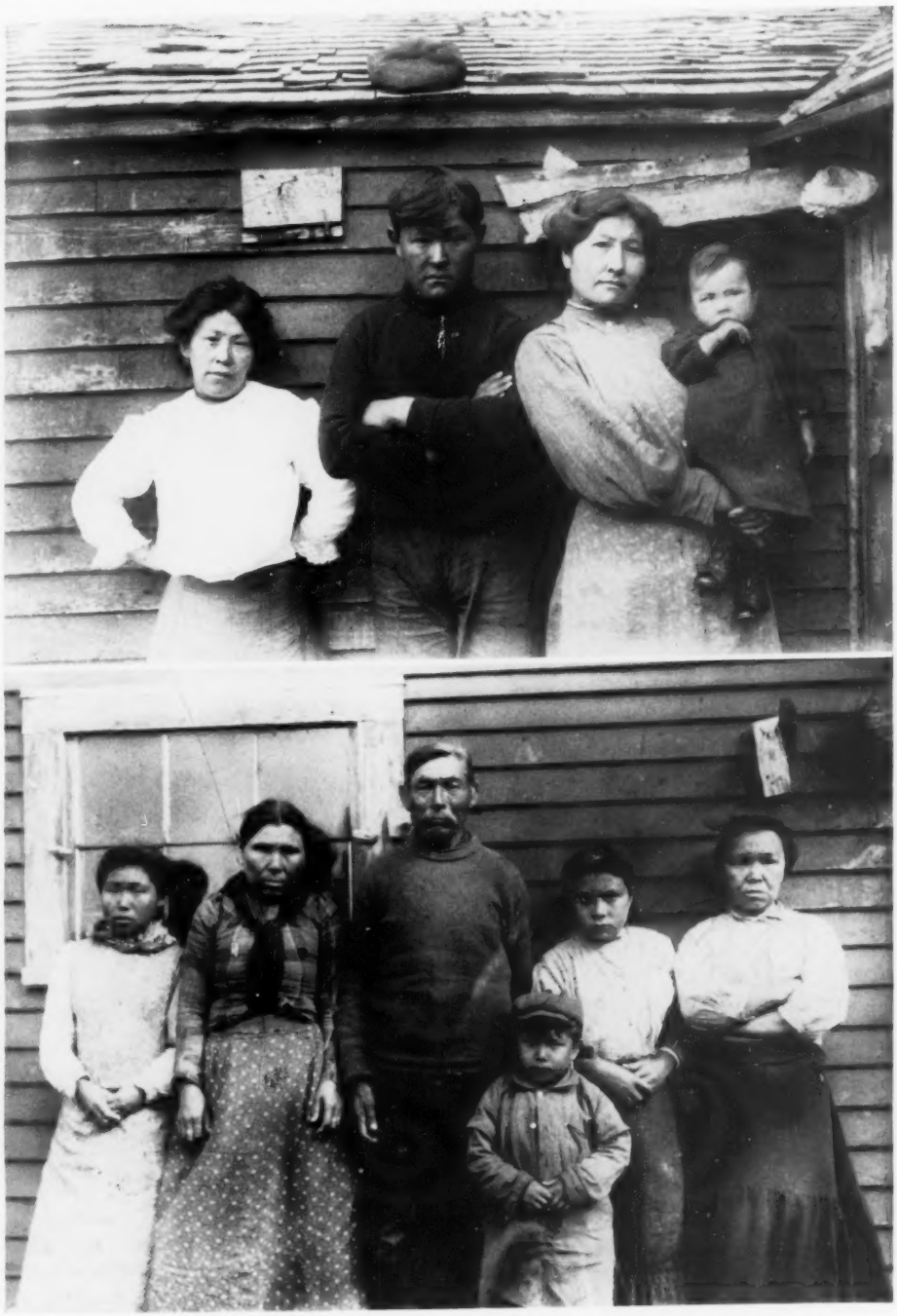
It now is generally admitted that North America originally was peopled from northeastern Asia by way of Alaska. This was a slow, unorganized migration extending over thousands of years and composed of small groups of physically and culturally diverse peoples of a basic, more or less mongoloid stock, who became the ancestors of the various Indian tribes and the Eskimos. This migration took various routes, one of which may possibly have been by way of the Aleutian Islands, stretching like a chain of stepping stones between the two continents.

Whether or not the Aleutians were an entry route into America, the islands constitute a rich hunting ground for the anthropologist. They are dotted with hundreds of sites of old villages, and the accumulations of these contain a buried record of their former inhabitants, both cultural and skeletal.

Physically the Aleuts stood alone. They belonged to the great yellow-brown racial complex, together with all the peoples of Eastern Asia, the Eskimo and the American Indian. They were among the broadest-headed races on earth. The ratio of the breadth to the length of the head, the so-called "cephalic index," is a hereditary character and one of the most useful tools of anthropologists in determining racial relationships.

Eskimos are a relatively narrow-headed people. The head breadth increases in general from Greenland westward, but even the Alaskan Eskimo has a considerably narrower head than that of the Aleut. Perhaps the nearest approach to the Aleut is found among the "Athabascans" of interior Alaska and Canada, presumably among the latest prewhite migrants to cross from Asia to North America. These northern Athabascans are related linguistically to the Navajo and Apache of the Southwest.

There are various theories to account for the anomalous position of the Aleuts among the American races. The most probable opinion is that they brought their characteristics from Asia.



FAMILY GROUPS OF TYPICAL ALEUTIAN ISLAND NATIVES

HUSBAND AND WIFE
GIRL 12 YEARS OLD AND HER HUSBAND, 60.

AN ALEUTIAN COUPLE
SERGEI SUVOROV AND HIS WIFE, AGNES, OF UMNAK.

Their language, usually divided into two or three dialects spoken respectively in the East, Middle and West of the island chain, is Eskimoid. It has no demonstrable relation to any of the Athabascan dialects, but many words show a close similarity to Eskimo, which itself is not closely related to any other living tongue.

The origin and meaning of the term "Aleut" are disputed. Bering in his reports referred to them only as "Americans." They used to call themselves "Unangans"—probably meaning only "the people." Dr. Hrdlička suggests

A FAMILY OF UMNAK

that the name is composed of Al and Ute, the latter being a general Eskimo term for "people."

At the time of Bering there may have been as many as 20,000 inhabitants on the desolate chain, their numbers being gradually reduced until to-day in the islands they count less than 1,000, and these all mix-bloods.

The government of the Czars at the start of the nineteenth century enacted protective laws for the Aleuts. The apostle to them was a Russian priest named Veniaminov, who must be considered one of the greatest missionaries of American history. He went to the

islands in 1824 and stayed for ten years. A man of much sincerity, zeal and energy, he was very successful, not only in Christianizing but also in civilizing the aborigines.

Almost entirely as a result of his work, the Aleuts became devout Greek Orthodox Christians; they remain so to the present and have not been receptive to missionaries of other creeds. The poorest Aleut to this day dutifully turns over part of his earnings to the church.

By and large, the Aleut has responded well to civilization. He is a man of fair intelligence. The "Aleut" of to-day wears modern clothes, lives in half a dozen little villages of fairly comfortable frame houses; there are few more loyal Americans than these islanders.

Recently the whole small population of the islands has been evacuated by our authorities to prevent them from falling into the hands of the Japanese.

N. M.

SPHAGNUM MOSS FOR USE IN SURGICAL DRESSINGS

In the last world war sphagnum moss was used by the Allied armies on a large scale as a substitute for absorbent cotton in surgical dressings. Its use in that connection was not a new practice; it was merely a revival of a very ancient European performance by country people utilizing mosses and moss peat as sanitary bedding and in the treatment of boils and discharging wounds of man and domestic animals. The material was extensively employed during the last Russian-Japanese war as a first-aid dressing. The Germans, however, demonstrated the value of sphagnum mosses and moss peat in modern, antiseptic methods of surgery. The Canadian Red Cross made over 200,000 moss dressings per month during the summer of 1918, and toward the end of the war the British used nearly a million moss dressings per month.

The American Red Cross officially adopted sphagnum moss as a standard dressing material in 1918 and used it in many American military hospitals. The work of collecting, drying and preparing mosses as pads for surgical dressings was organized in the eastern United States under the leadership of Harry James Smith, of New York, and Dr. Geo. E. Nichols, of Yale University. On the west coast the enterprise was led by Professor J. W. Hotson, of the University of Washington, while in Canada the work was done under the direction of Dr. J. B. Porter, of McGill University.

Advantages of sphagnum moss for surgical dressings. The advantages of a suitable type and quality of sphagnum moss or the peat derived from it, are its high absorption capacity, ranging from 15 to over 30 times the dry weight of the organic material, its sponge-like matting, porosity, softness, elasticity, lightness and strong acid reaction. The secret of the efficiency as an absorbent—taking up liquids much more rapidly and in amounts greater than four times as much as absorbent cotton—lies in the microscopic structure of the leaves of mosses.

Distinguishing characteristics. Not all species of sphagnum mosses or types of moss peat are of equal value for use in surgical dressings. The larger number of the 40 different species in North America is practically of little value for this purpose. Their absorbency is low, ranging from 7 to 10; the plants are comparatively delicate and even with careful handling the leaves and branches break off, are usually brittle when dry and tend to crumble or produce a fine dust. Only the species which form dense foliage and close-set branches exhibit a high capacity for absorbing liquids and possess soft texture and the qualifica-

tions, specified above, of value in surgical dressings. The most promising species, in the order named, are *Sphagnum magellanicum*, *S. papillosum*, *S. imbricatum*, *S. palustre* and to a less extent, *S. fuscum*, *S. medium* and *S. compactum*. A few of these mosses as well as the peat derived from them are illustrated in Figs. 1 and 2 of the U. S. Department of Agriculture Circular 167, copies of which may be consulted in public and college libraries. *Where found.* Sphagnum mosses are cosmopolitan in their distribution and widely distributed in Eurasia as well as on this continent, including Alaska. They grow best in regions where the climate is moist, where fogs are frequent and summers are cool; they develop luxuriantly near the seacoast, and are more abundant northward than southward. Sphagnum mosses depend upon rainfall for moisture. They are confined to poorly drained areas of peat known as bogs or muskegs, in which trees are usually dwarfed and scattered. The shrubby undergrowth is low and consists predominantly of such heaths as Labrador tea, bog rosemary, laurel, blueberry, cranberry and others. Almost invariably sphagnum mosses constitute a hummocky ground cover with scattered sedges, insectivorous pitcher plant and sundew, and cottongrass. The moss vegetation extends in a well-preserved condition often to a depth of a foot or more below the surface and has either a raised dome-shaped contour or the form of a flat quaking and floating mat. Dry firm bogs which have a more or less tall bushy cover and wooded fringes around the margin of the peat area or swampy forests are least favorable for the growth of mosses.

Information wanted regarding local supplies of sphagnum moss and moss peat. In the last war instructions were issued by Professors Hotson and Nichols in joint agreement with the American Red Cross. Arrangements provided for locating as many good bogs as possible and to explore them; to note their size and accessibility to roads, the purity and amount of moss present, and to collect small samples of surgical moss and moss peat or "peat moss" in selected areas and in different portions of the bog. The material was collected by hand from the surface to a depth of one foot below the surface or to a depth where decay was observed. Each sample was cleaned of twigs and "weeds," gently squeezed to remove surplus water, packed in gunny sacks and labeled with a number and with the name of the locality. In this manner supplies were early located and made up into a monthly output of surgical dressings exceeding 20,000 pads for American war hospitals. Half a million sphagnum moss dressings were prepared for the Italian army.

There is a possibility that during the present emergency surgical dressings again may be required in hospital work in Alaska, Canada and elsewhere on this continent, or for shipment to less favored communities. Hence it seems advisable to anticipate and to prepare for supplying demands for sphagnum moss pads.

A. P. Dachnowski-Stokes